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FURTHER STUDIES ON CEREAL RUSTS IN INDIA, PART I.

BY

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FURTHER STUDIES ON CEREAL RUSTS IN INDIA

CONTENTS

PREFACE

INDIA is the largest wheat producer in the British Empire and it is unnecessary, therefore, to lay stress on the importance of the cereal-rust problem to this country.

Prof. K. C. Mehta has been engaged on research on different aspects of this problem for a period of nearly 16 years and has already published summarized accounts of his work from time to time. He has now written up a great part of his researches. The original intention was to publish this work as a series of papers in the *Indian Journal of Agricultural Science*, hence they have been prepared in the form of three large communications. The Editorial Committee of the Imperial Council of Agricultural Research, under whose auspices this work has been continued since the year 1930, later decided to publish them as a Scientific Monograph so as to give a connected account of ' Further Studies ' conducted up to March, 1938.

W. BURNS, D.Sc., C.I.E., I.A.S.
Agricultural Commissioner with the Government of India.

SIMLA,
June 23rd, 1939.

GENERAL INTRODUCTION

THIS introduction has been written in accordance with the decision of the Indian Council of Agricultural Research to publish the account of 'Further Studies on Cereal Rusts in India' in the form of a Scientific Monograph.

A study of the annual recurrence of rusts of wheat and barley in the plains of India was started by me in the year 1923. For want of financial assistance, I had to continue this work for a period of nearly seven years at a considerable personal expense. A brief account of that work was published as my Presidential Address to the Botany Section of the Indian Science Congress in the year 1929.

In the following year, the Indian Council of Agricultural Research kindly sanctioned a grant for equipment, maintenance of laboratories as well as for salaries of the research staff required for my assistance. This grant was followed by two others making up a total of Rs. 2,43,776 up to the end of March, 1938.

With the help of these grants, temporary laboratories were started at Agra, Simla and Almora. Besides that, several fresh graduates with special knowledge of mycology were engaged temporarily to assist me in this work. The scope of the study was enlargea from time to time as would be clear from the following statement :

During the years 1930-33, there were only three assistants, one for the laboratory at Simla, another for the laboratory at Almora and the third for the study of incidence of rusts in other parts of the country. A preliminary study of physiologic races of black and brown rusts of wheat was also started in November, 1931, for which a small additional grant was made and one assistant added to the staff.

In 1933-35, two more assistants were appointed and the study of physiologic races was further extended.

From April 1935 to March 1938, in addition to the previous items of work on the rôle of alternate hosts, physiologic races, oversummering and overwintering of rusts, their incidence in the plains as well as hills, there was included in the programme survey of rusts in the Punjab, Bombay-Deccan and the Madras Presidency, under the direct supervision of officers in the Provincial Departments of Agriculture concerned, in co-operation with me. As a part of this scheme, the Imperial †Economic Botanist also started work on the breeding of wheats resistant to rusts in co-operation with me. During this period, therefore, as many as 12 assistants were employed.

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Arrangements were also made for a period of nearly seven years for the exposure of aeroscope slides at a large number of stations, for some time up to 54, in connection with the study of rust dissemination. A Meteorological Assistant was maintained for five years to prepare wind-trajectories for representative stations in this connection and he also looked after the exposure of cellophane strips flown on kites from the Agra Observatory for catching spores of rusts.

Morphological studies of leaves of some of the species of *Berberis* in relation to their susceptibility to sporidia of black rust of wheat have also been in progress for nearly three years.

The programme of work also included tests for seedling resistance with a large number of wheat varieties, indigenous as well as foreign. These tests were made with single spore cultures of the physiologic races of each of the three rusts of wheat. Selected varieties were also tested for adult resistance to black rust.

With the expansion of the scope of work in the year 1933, arose the need of relief to me from a part of my duties at the Agra College and the Indian Council of Agricultural Research very kindly allowed an adequate sum out of the grant to be spent in that direction. I wish to express my warmest thanks to the authorities of the Agra College for the facilities provided for this work as well as for the relief granted to me from some of my duties as a whole-time member of the staff of that institution.

It is my very pleasant duty to offer sincerest thanks to the Indian Council of Agricultural Research for the handsome grants-in-aid given for this work. The officers of the Council have been very kind and accommodating and my sincere thanks are also due to them.

In view of the international importance of the problem under reference, I have consulted Prof. F. T. Brooks, F.R.S., of the University of Cambridge; Sir Edwin J. Butler, F.R.S., now Secretary, Agricultural Research Council, London; and Prof. E. C. Stakman of Minnesota, U. S. A., from time to time during the progress of the investigations and wish to express my most grateful thanks for their kind interest and helpful suggestions.

My sincere thanks are also due to the following workers who have given me the benefit of their opinion on certain aspects of the problem under report :—

Prof. A. H. R. Buller, F.R.S., of Manitoba; Sir Arthur Hill, F.R.S., Director, Royal Botanic Gardens, Kew; Sir John Russell, F.R.S., Director, Rothamsted Experimental Station; Prof. V. H. Blackman, F.R.S., London; Drs. J. H. Craigie and Miss M. Newton of the Dominion Rust Research Laboratory, Winnipeg; Prof. G. Gassner, Ankara; Dr. W. Straib of Braunschweig, Germany; Dr. C. O.

Johnston of Agricultural Research Station, Kansas, U. S. A. ; Dr. W. L. Waterhouse, Sydney ; Dr. J. Ramsbottom, Keeper of Botany, Natural History Museum, London, and Mr. A. D. Cotton of the Kew Herbarium.

The kind help given by a large number of other workers in India and abroad as well as the loyal assistance rendered by the Research Staff are duly acknowledged in the different sections comprising this monograph.

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RUST RESEARCH LABORATORY,
SIMLA E.,
29th June, 1939.

SECTION I.—PHYSIOLOGIC RACES

(With Plates I-V, two maps and two text-figures)

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PART TWO : PHYSIOLOGIC RACES OF *PUCCINIA GRAMINIS TRITICI* (PERS.) ERIKS. & HENN.

PART THREE : PHYSIOLOGIC RACES OF *PUCCINIA GRAMINIS AVENAE* (PERS.) ERIKS. & HENN.

PART FOUR : PHYSIOLOGIC RACES OF *PUCCINIA TRITICINA* ERIKS.

Part Five : Physiologic Races of *Puccinia glumarum* (Schm.) Eriks. & Henn.

Summary

PART ONE

General

1. Introduction

In India, wheat suffers from all the three rusts, i.e., black, brown and yellow, caused respectively by *Puccinia graminis tritici* (Pers.) Eriks. & Henn., *P. triticina* Eriks. and *P. glumarum* (Schm.) Eriks. & Henn. The black and yellow rusts are also found on barley. Black rust of oats, caused by *P. graminis avenae* (Pers.) Eriks. & Henn. has been met with only in the Nilgiris, so far.

Over the greater part of the country, these crops are sown during October-November and are harvested in March-April. In the hills, harvesting is done one to two months later. Oats are grown only for fodder and over a very small area.

A study of the Annual Recurrence of Rusts of wheat and barley in the plains of India was started by the writer in the year 1923 and a brief account of that work was published six years later [Mehta, 1929]. This was followed by another article [Mehta, 1933], giving an account of further progress of investigations on different aspects of the Cereal-rust problem of this country.

In the study of physiologic races of the four rusts under reference, some of the research assistants rendered valuable help and others assisted in the routine connected with this highly laborious work. Mr. R. Prasada, once a student of the writer and now Assistant Mycologist in the scheme of Investigations on Cereal Rusts, deserves special mention of his loyal co-operation and ungrudging assistance throughout the period of these studies. Mr. H. L. Gulatia assisted in this work from time to time since the year 1932 and Mr. J. L. Merh for the last three years. Mr. A. N. Sawhney, Dr. K. P. V. Menon, Dr. G. T. Kalé and Mr. D. D. Gupta also helped in this study for short periods.

2. Scope of the present investigation

On an average, there are 33 million acres under wheat and another 8 millions under barley in this country each year but unfortunately the area under improved varieties is very small (less than 20 per cent). The bulk of these crops, therefore, is raised from the un-improved, indigenous (*desi*) varieties, which are very heavily susceptible to rusts. As a matter of fact, there is hardly any, even amongst the improved varieties, that could really be called 'rust resistant.' This is due to the fact that the popular wheats of India were selected or bred at a time when nothing was known regarding the occurrence of physiologic races within any of the three morphological species of the genus *Puccinia*. For instance,

black rust of wheat was then regarded as one single strain and was supposed to possess the same pathogenicity irrespective of the place, country or continent, wherefrom it was collected.

Consequently, the breeding of wheats from the point of view of rust resistance has to be done afresh, paying due attention to the different physiologic races that might be occurring in the country. Work on these lines has been in progress outside India for several years and the writer felt that the study of physiologic races was long overdue. This aspect of the Investigations on Cereal Rusts was, therefore, added to the programme in the year 1932.

Considering the distribution of each of the three rusts of wheat in this country, the writer was convinced of the need of a simultaneous study of the physiologic races of all of them. In this connection, it might be stated that black stem-rust is found in all parts of the country, hills as well as plains. The brown rust also occurs everywhere, excepting a small part of Peninsular India and the yellow rust is common over 90 per cent of the area under wheat. It is absent only from the plains of Peninsular India because of warmer weather.

As stated in the publications referred to above, yellow and black rusts are also found on barley but the dwarf rust of this host (*P. simplex*) is very rare in this country and was, therefore, not included in the programme of work, which was heavy even otherwise. Black rust of oats was found for the first time in India during the course of the present studies and occurs only in the Nilgiris.

This section deals with the Physiologic Races of the following rusts, as found in the uredostage :—(i) *P. graminis tritici*, (ii) *P. graminis avenae*, (iii) *P. triticina* and (iv) *P. glumarum*.

A. Specialization within P. graminis *(Pers.)*

Black rust found during these studies on barley, *Bromus patulus*, *Avena fatua* and *Brachypodium sylvaticum* respectively, was put on rye in order to make sure if *P. graminis secalis* occurred on any of these hosts. Rye was weakly infected in every case but on subsequent inoculations on this host the cultures were lost.

Barley and all the three grasses mentioned above, have proved to be collateral hosts of *P. graminis tritici* in this country and some of the physiologic races of the latter have been found on them. This 'Specialized Form' has also been found to infect rye, because in recent experiments two out of its six physiologic races occurring in India produced weak infection on that host. Stakman and Piemeisel [1917] have also recorded that rye is weakly infected by *P. graminis tritici* in U. S. A. From inoculations with stock samples of black rust of wheat in England, the writer [Mehta, 1928] concluded that rye was not susceptible to it. Waterhouse [1929 ; 1934 ; 1936] has reported the occurrence of *P. graminis tritici* on rye in Australia.

B. Specialization within P. glumarum *(Schm.) Eriks. & Henn.*

In the last article [Mehta, 1933], it was reported that the yellow rust of wheat had failed to infect barley and *vice versa.* That conclusion was arrived at after inoculations with stock samples only, because till then no physiologic races of this rust had been identified in this country. After their isolation, single spore cultures of seven physiologic races of yellow rust of wheat were recently put on some varieties of barley (Pusa Type 1, Pusa Type 21, a Nepalese variety, Simla local and Agra local) using Agra local wheat as a control. Out of these, the Nepalese variety proved to be susceptible to six races, Pusa Type 1 to only one, Type 21 to three, Simla local to four and Agra local to six of them.

On barley, so far only one physiologic race of this rust has been found. This was put on six varieties of Pusa wheats, Simla local red, Simla local white, Agra local, with Agra local barley as control. Some of the Pusa wheats were weakly infected whereas both the Simla varieties as well as Agra local proved to be moderately susceptible.

It is only right, therefore, to conclude that some of the physiologic races of this rust on wheat can infect barley and that the only race found on the latter so far, is able to infect some of the wheat varieties. Gassner and Straib [1934], after a study of collections from wheat, barley and *Agropyron repens*, came to the conclusion that there are no 'Specialized Forms' within the morphological species, *P. glumarum*, as recorded by Eriksson [1894]. Newton and Johnson [1936], after their studies of this rust in Canada, expressed agreement with Gassner and Straib's views.

3. METHODS OF STUDY

Material for these studies was collected by the rust research staff as well as other workers from a large number of stations in different parts of the country. Rust collections were air-dried for 24 hours in a room and then despatched in manilla envelopes by post to the laboratory at Agra or Simla, where they were put in a refrigerator at 5°—10°C.

Ordinarily, such collections as could not be handled immediately were repeated once in three months on Agra local wheat to maintain their viability, till needed for study. The Agra local wheat (an un-improved indigenous or *desi* variety of *T. vulgare*) had been observed by the writer to suffer heavily from all the three rusts for a number of years. This variety was used as control during preliminary work of 1931-32 as well as for detailed studies carried out in the following year, when most of the collections were put directly on the differentials. Every collection as well as isolation therefrom, produced very heavy infection on this variety. Throughout the present studies also, this variety was used as control for inoculations with all the collections as well as their isolations and no case of resistant reaction was noticed on it.

In the case of black and yellow rusts of barley and the black rust of oats also cultures were repeated, whenever necessary, on susceptible local varieties.

Till recently, the seed of differential hosts, in the case of all the rusts under report, was obtained from abroad and it was not possible in every case, considering the limited supply of seed and the number of collections that had to be studied, to sow more than six or seven seeds of each differential for inoculations with stock cultures. Sometimes it happened that only three or four seedlings came out because of poor germination but this difficulty was overcome by inoculating a complete set of differentials again with suitable isolations, before final conclusions were drawn regarding the identification of a race.

Seedlings were sprayed with water and inoculations made on the first leaf, with a blunt lancet needle. As far as possible, only fresh cultures or those clipped one to two weeks earlier, were used for inoculations. Each collection was thoroughly mixed before being put on the differentials and a small quantity kept in a moist chamber for a test of its viability, which was recorded on the following day. After inoculation, all the pots containing the seedlings were put on a wet sand-bed in a large tray and covered with a glass case, the interior of which was sprayed heavily with water. Two days later, all the pots were removed to benches in the green-house, where good diffused light was available throughout the day. Except occasionally during the monsoon at Simla, the need of artificial light was never felt.

Ordinarily, the length of the incubation period was found to range between 7--10 days and the reactions on differential hosts were recorded a week after the appearance of the rust on any of them. In the case of yellow rust, it was felt necessary to wait for a couple of days longer before recording the results.

The procedure adopted for detailed study and analysis of each collection was decided after consulting the analytical keys of Stakman and Levine in the case of black rust; Johnston and Mains and later on Humphrey, Johnston and Caldwell's key for brown and Gassner and Straib's key, Straib [1937], for yellow rust. Keys for black and brown rusts of wheat have not yet been published by their authors. The writer got cyclostyled copies, on request.

For interpretation of types of infection in the case of each rust, due attention was paid to the explanation of symbols used respectively in the keys mentioned above.

It might be mentioned, that at least one isolation was selected and tested on a complete set of differentials even in such cases, where the stock collection produced types of infection, typical of a particular race on each of them.

All single spore cultures were started by picking up a solitary spore under a binocular dissecting microscope, with a glass needle. The method has been fully described by Newton and Johnson [1932]. /

4. Equipment

In a tropical country, the difficulties of growing cereal rusts in a greenhouse are obvious. Over the greater part of the plains of India, for nearly seven months in the year (April-October) it is almost impossible to lower the temperature inside a greenhouse to the range congenial for rust development. At the commencement of preliminary work on physiologic races in November, 1931, it was felt that for a proper control of temperature the interior of the greenhouse, which was constructed for this work, would need cooling even during winter. Necessary alterations and arrangements for the control of temperature were made and all greenhouses built later were provided with cooling devices, designed by the writer, for lowering temperature to a suitable range.

Each greenhouse was provided with a full-length chimney at the top for the exit of hot air but a double-muslin ceiling, with a space of 1—2 in. between the two sheets, was inserted below the roof all round in order to keep out wind-borne infection.

Cool air was introduced into the greenhouse with the help of ventilating fans and *khus* boxes, made of thickly woven roots of *Andropogon muricatus.* These roots are commonly used in making creens for cooling rooms during summer in the plains of this country. Each *khus* box was fitted, with the open side facing the greenhouse, in a window at ground level and a fan was placed in each box. In order to keep out wind-borne infection, every *khus* box was carefully closed on the top and below and covered on all the three sides, made of *khus,* with double muslin. During the day-time, when fans were usually needed, all the *khus* boxes were constantly kept wet on the outside.

Direct sun was kept out by the use of thin bamboo-stick screens on the top as well as the sides, as found necessary. The muslin ceiling was sprayed with water to lower temperature or raise humidity, whenever needed.

During warm weather, the water used for *khus* boxes had also to be cooled with ice.

By these means, the temperature of each greenhouse was maintained, without a draught, within the range of 60°—75°F. during the day-time. Even on warm days, the maximum seldom exceeded 80°F., which is nearly the highest reached in shade on the plains, during the greater part of winter. This range was found by experience, during the preliminary studies of 1931-32, to be the most congenial for development of infection with black and brown rusts. In the case of yellow, which flourishes better in cool weather, the temperature of the greenhouse was never allowed to exceed 70°F. Humidity seldom fell below 60 per cent during the day.

The entrance to each greenhouse was controlled by two or three trap doors. In order to safegua d against chinks due to cracks in the glass putty, a velvet ribbon was inserted, all along the edge of every glass pane fixed on the doors and

wall of the seedling house as well as all the greenhouses that were constructed for these studies. The glass putty was replaced as soon as any cracks were noticed.

In order to study a fairly large number of collections, keeping in view the need of a simultaneous study of all the three rusts, greenhouses had to be constructed later on at Simla also, for this work during summer (April-October). Between the laboratories at Agra and Simla, it was possible, therefore, to carry out the study of physiologic races of black and brown rusts all the year round. Even at Simla, greenhouses had to be cooled throughout summer as well as on sunny days early in winter and during spring. Work on yellow rust was done only at Simla during winter.

The greenhouse benches were partitioned into separate compartments by double-muslin screens with a space of 1 in. between the two sheets. In the black-rust greenhouse (Plate III), on account of a full-length glazed screen (central partition), muslin curtains were used only in the case of tests with single spore cultures or when collections from distant areas happened to be placed in adjacent compartments.

In the case of single-spore culture house (Plate IV), a double-muslin case was used for each culture. Each case was fitted with a watering tube containing a cotton-wool filter and cases covering cultures of different physiologic races of the same rust were always kept apart.

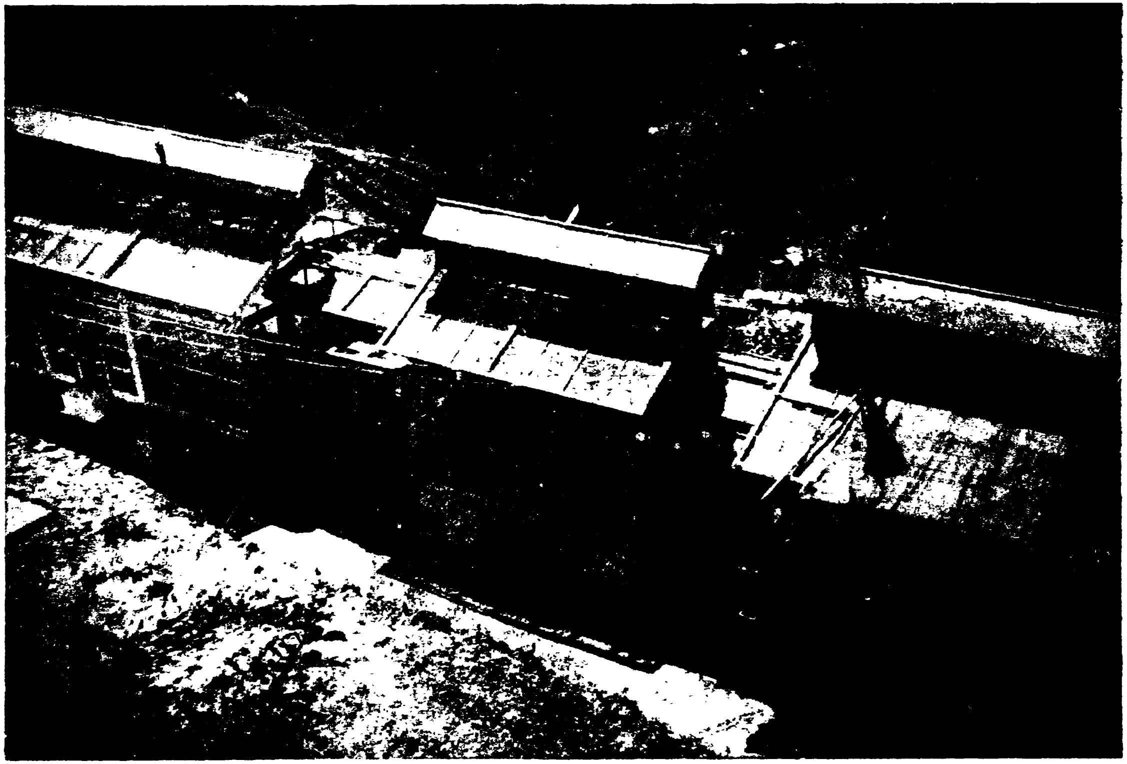
A pot containing uninoculated seedlings of Agra local wheat was always kept as control in the seedling house as well as in every greenhouse. Constant records of temperature and humidity inside the greenhouses were kept with Edney thermohygrographs.

The three greenhouses at Simla, connected by covered and glazed passages are shown in Plate I; the plan of all the three, passages, trap doors, sliding doors, *khus* boxes, etc. in Fig. 1; the interior of two greenhouses in Plates II and III; and section of one with muslin ceiling, chimney, *khus* box and a fan in Fig. 2.

5. Area covered by these studies

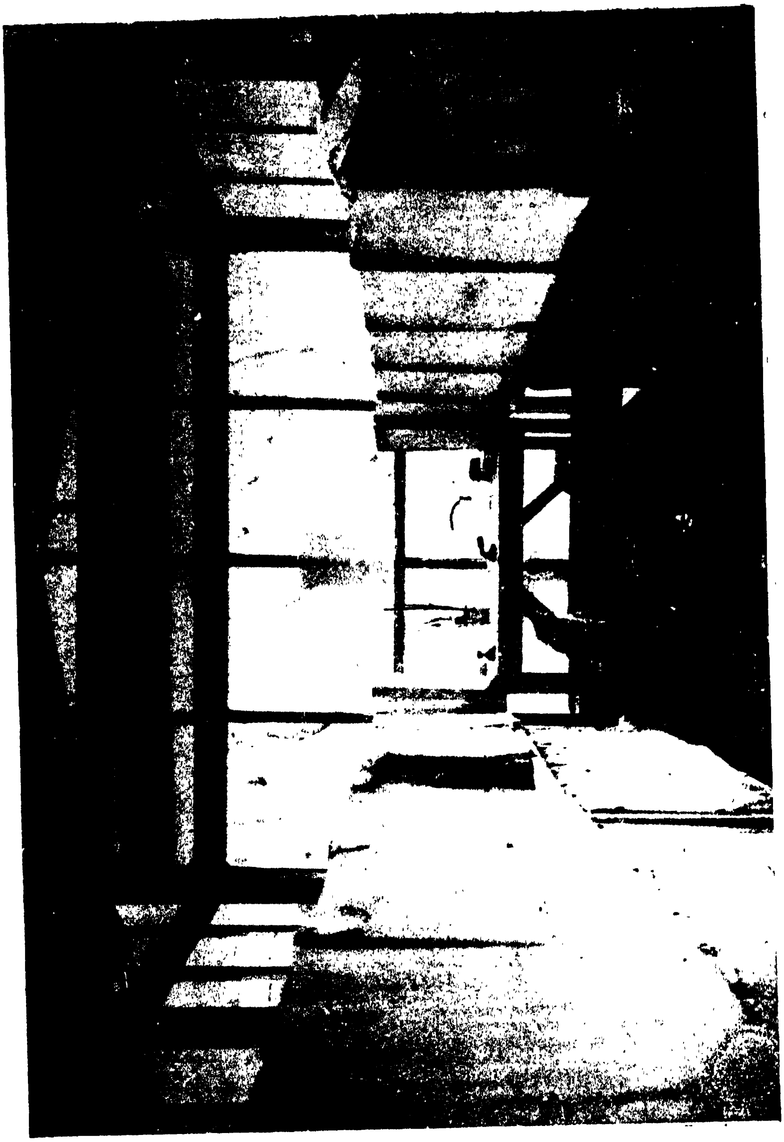
It would be clear from tables given in Parts Two, Four and Five, that collections were obtained from practically the whole of the wheat area. As far as possible, the number of collections from different provinces and states selected for study was fixed in accordance with the acreage under wheat in those areas. In the case of those stations, wherefrom only a few collections were received, all were included for study.

For the sake of convenience of reference, the country has been divided into five areas and the boundaries of each are shown in Map No. 1. The names of different provinces, States and the more important towns are shown in Map No. 2.



Photograph of three greenhouses at Simla connected by covered and glazed passages. Three *khus* (*Andropogon muricatus*) boxes, used for cooling the greenhouses can be seen on the outside. There is a full-length chimney at the top of each greenhouse. The central structure is the seedling house.

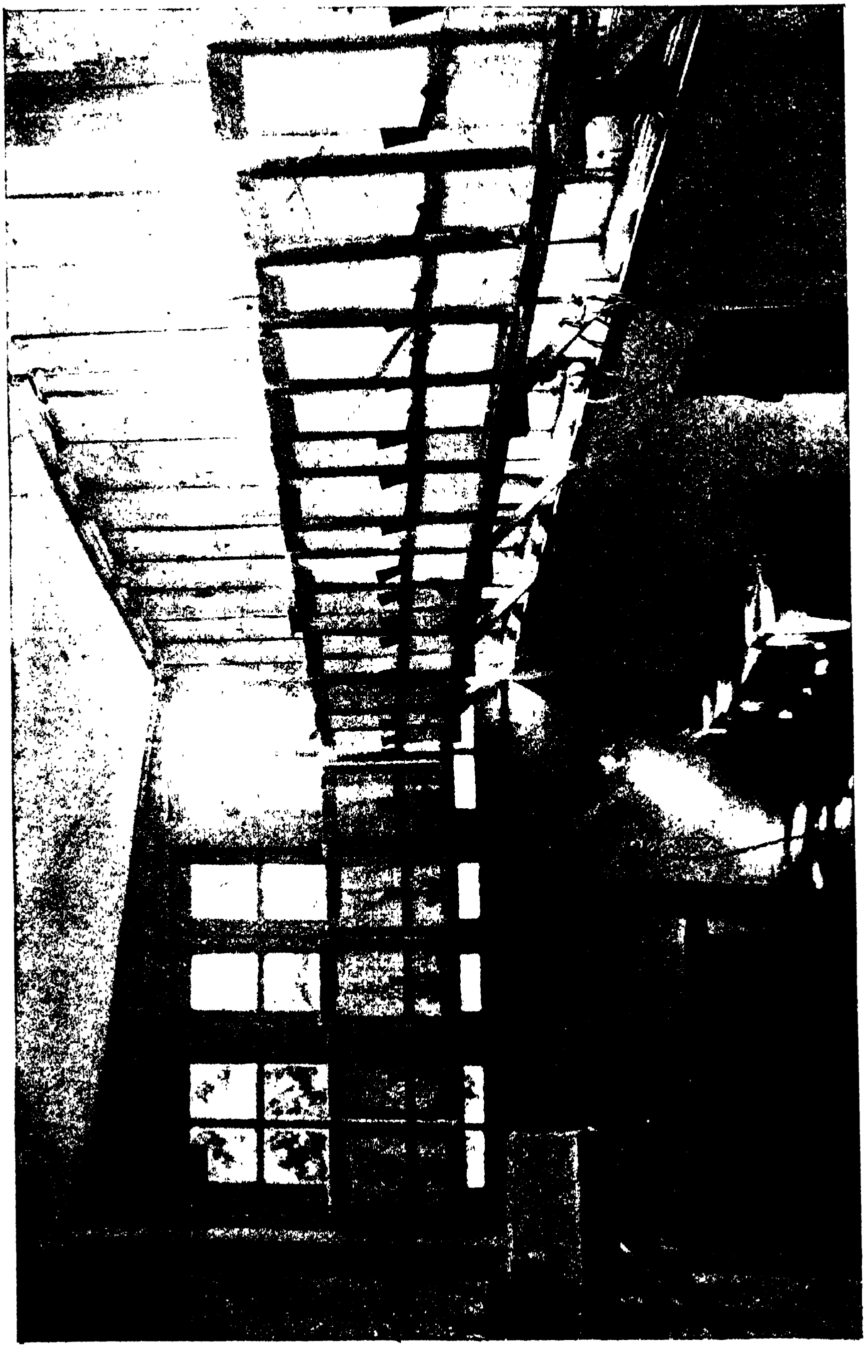
PLATE II



Interior of the brown rust greenhouse

PLATE III

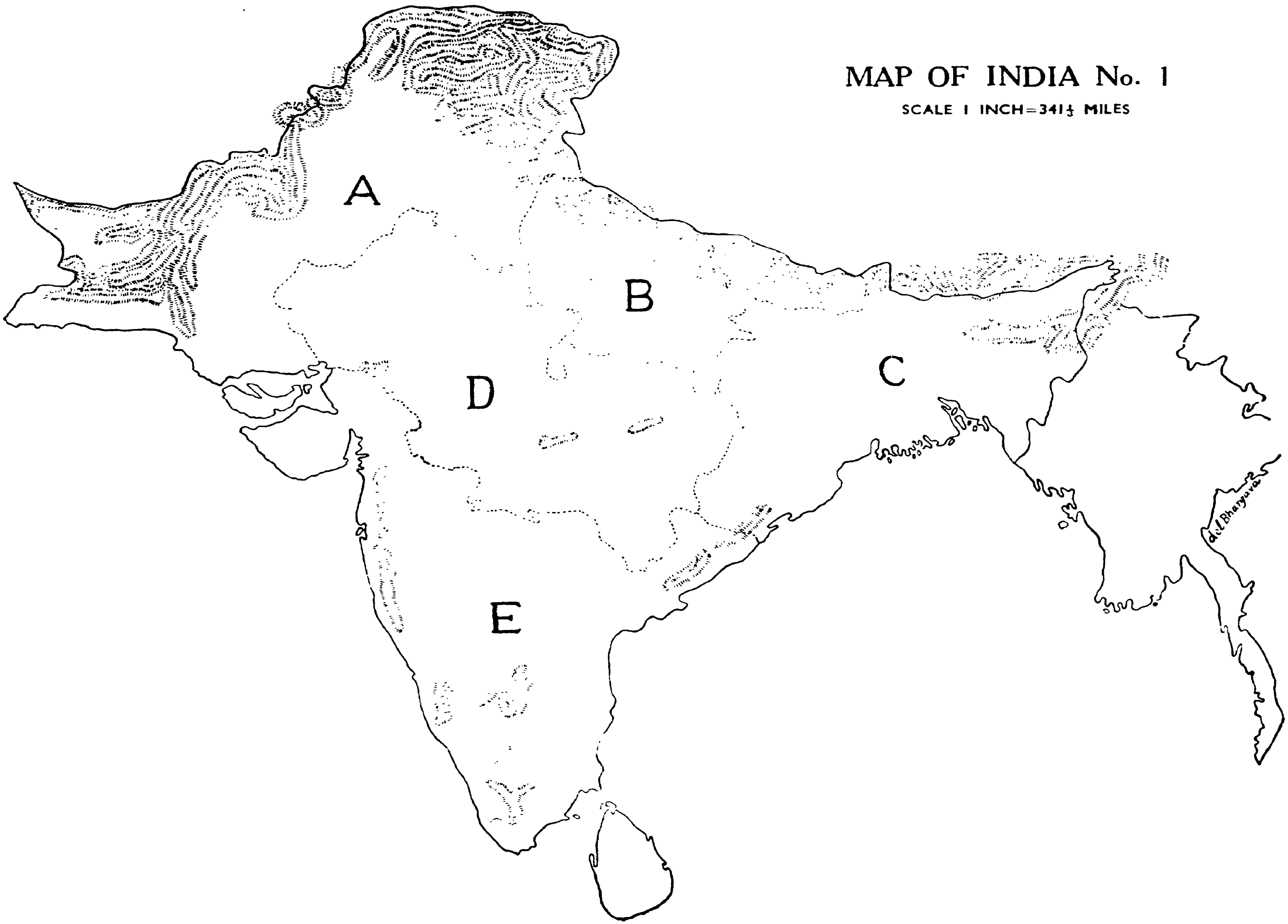
PLATE IV



Interior of single spore culture house

MAP OF INDIA No. 1

SCALE 1 INCH=341⅓ MILES



MAP OF INDIA No. 2

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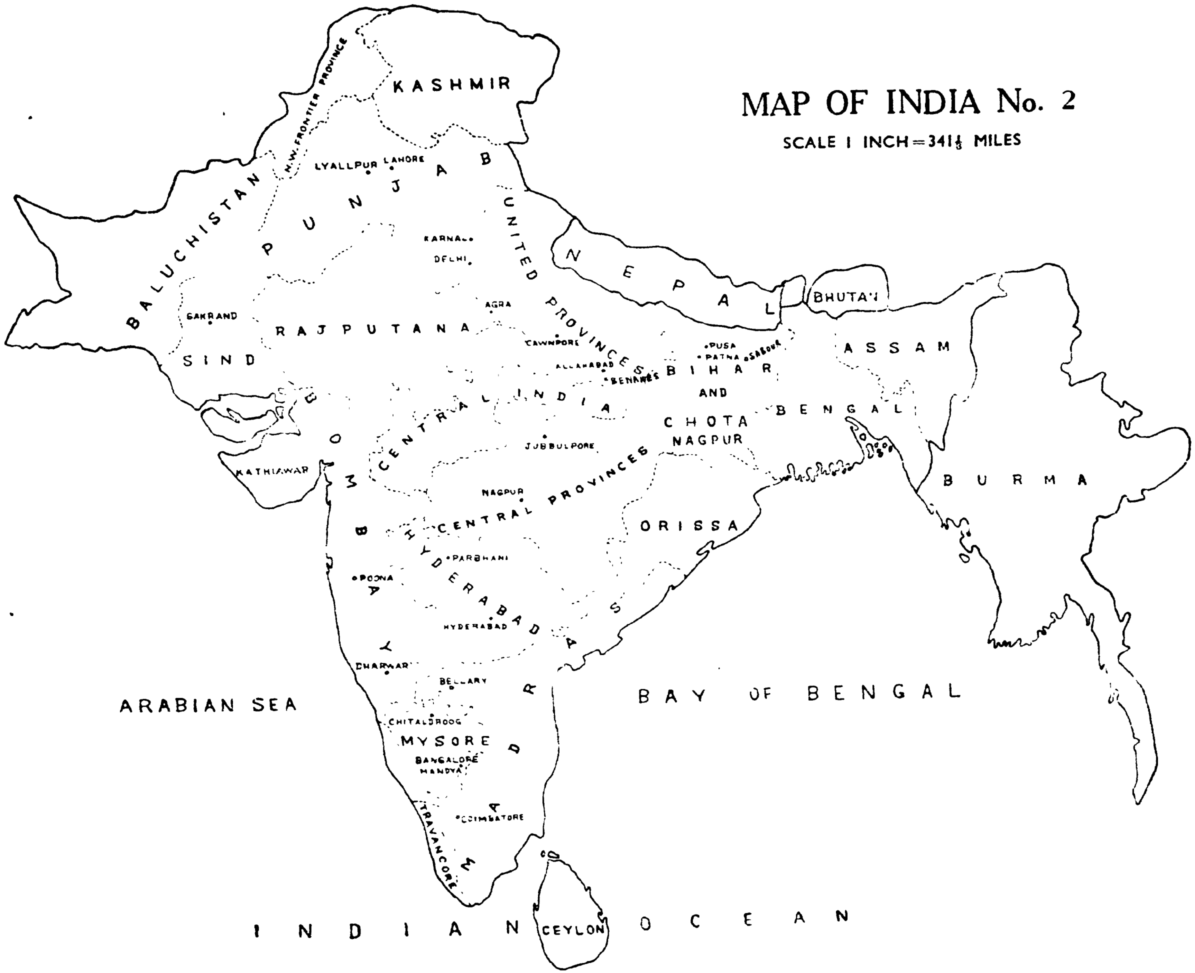

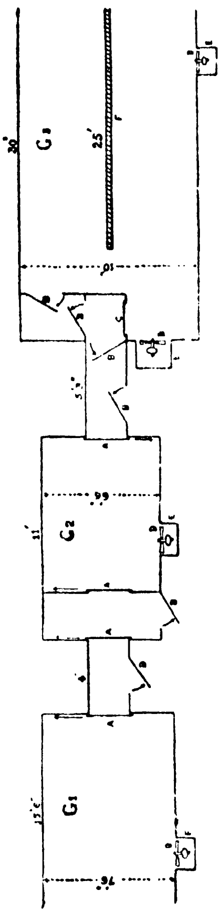

1. Ground plan of the greenhouses and passages. G1 and G3—greenhouses for the study of brown and black rusts. These greenhouses are used only for work on yellow rust during winter. G2—Seedling house. A—Sliding doors; B—Spring doors; C—Window sliding upwards; D—Ventilating fans; E—*Khus* boxes (made of the roots of *Andropogon muricatus* covered with double muslin); F—Central partition in the large greenhouse.

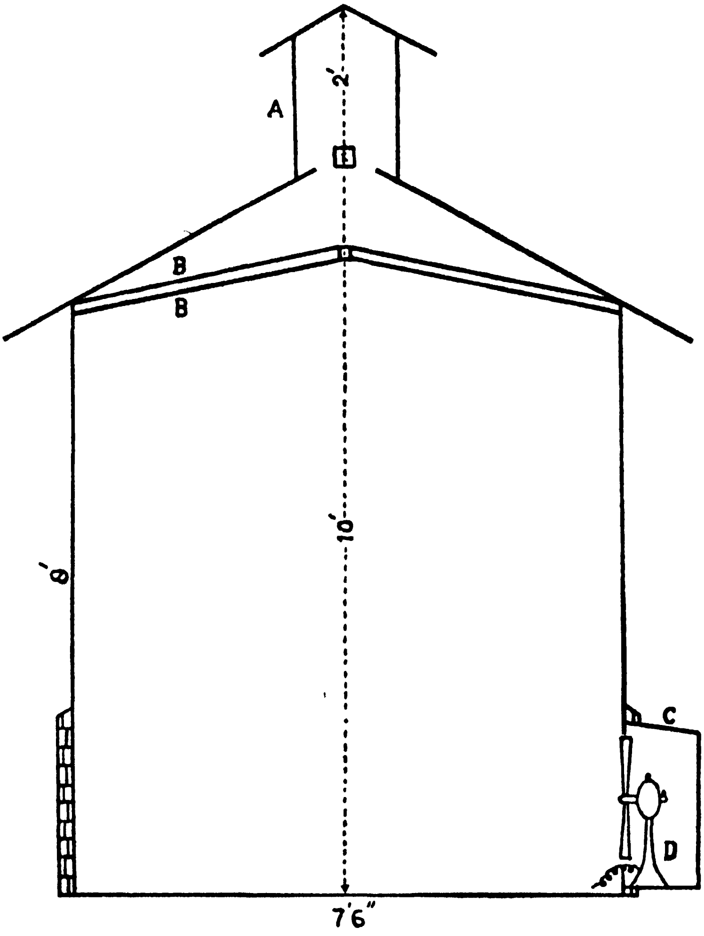

FIG. 2. Section of Brown Rust greenhouse. A—Full-length chimney; B—Muslin ceiling, two layers; C—*Khus* box; D—Ventilating fan.

6. Acknowledgments

1. The writer wishes to express his warmest thanks to the following workers for their kindness in supplying seed of differential hosts and analytical keys for the identification of Physiologic Races :

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*Head of the Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi.

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PART TWO

Physiologic Races of *Puccinia graminis tritici* (Pers.) Eriks. and Henn. (Black stem-rust of wheat, barley and wild grasses)

8. Review of literature

In some of the recent publications, including a monograph by Lehmann, Kummer and Dannenmann [1937], an historical review of the subject under reference has already been given. It is unnecessary, therefore, to discuss in detail the classic researches of Eriksson on the Specialization of Parasitism in Rusts of Cereals or the pioneer work done by Stakman and his co-workers [1917 ; 1919] on the Biologic Forms of *P. graminis* on cereals and grasses.

All contemporary work on the physiologic races (formerly known as biologic or physiologic forms) of *P. graminis* Pers. (black stem-rust) in different parts of the world has been carried out on the lines indicated by Stakman and Levine [1922] who, by the methods described in the first bulletin, were able to identify as many as thirty-seven different races of this rust on *Triticum* spp.

Newton [1922] recorded the occurrence of fourteen physiologic races in Canada, all of which had been previously reported from U. S. A. as well.

During the next eight years or so, Newton and Johnson [1927 ; 1932] and Newton, Johnson and Brown [1928 ; 1929 ; 1930] found twenty-seven more races, some of which were new.

Peltier and Thiel [1927] recorded sixteen physiologic races, one of which was new, from Nebraska and later Peltier [1933] found, in addition, four races in Kansas and Nebraska.

In Australia, Waterhouse [1929, 1, 2] came across seven races of this rust. McDonald [1931 ; 1933] found four races in Kenya.

Eight physiologic races, two of which were new, were reported from Bulgaria by Dodoff [1933-34].

In South Africa, Verwoerd [1931 ; 1935] met with eight races, including three that had not been found elsewhere.

From India, the writer [Mehta, 1933] reported the occurrence of four physiologic races from a study of thirty-five samples of this rust, collected from hills as well as the plains.

Tu [1934] found six races, four of which were new, from Kwantung (S. China).

In the year 1935, Stakman and Levine issued a revised key for the identification of 144 physiologic races of this rust that had been found to occur in different countries till then.

In Australia, Waterhouse [1935] came across one more race, bringing the total number to eight.

Sibilia [1936] reported the presence of two races in Italy.

Hassebrauk [1937] studied sixty samples mostly from Germany and a few from Belgium, Finland, Czechoslovakia, Hungary, Bulgaria, Italy, Greece and Turkey and identified fourteen different races, three of which are not recorded in Stakman and Levine's list of the year 1935.

The occurrence of a new race has recently been reported from Italian East Africa, by Sibilia [1938].

In a recent article, Waterhouse [1938] reported the occurrence of another race in Australia. The same author identified four races from rust material obtained from New Zealand.

9. Differential hosts

As in other countries, the differential hosts originally selected by Stakman and Levine [1922] were used for these studies. The list is as follows

Triticum compactum	... Little Club.
Triticum vulgare	... Marquis, Reliance and Kota.
Triticum durum	... Arnautka, Mindum, Spelmar, Kubanka and Acme.
Triticum monococcum	... Einkorn.
Triticum dicoccum	... Vernal and Khapli.

10. Types of infection

The symbols (0, 1, 2, 3 and 4) are the same as were used by Stakman and Levine to indicate the different types of infection. The explanation of the symbols, as given by those authors, is summarized below :

0 ... *Immune*—No uredinia (uredo-sori), hypersensitive flecks.

1 ... *Very resistant*—Uredinia minute and isolated, surrounded by necrotic areas.

2 ... *Moderately resistant*—Uredinia isolated and small to medium in size, hypersensitive areas present, pustules (uredo-sori) often in green islands.

3 ... *Moderately susceptible*—Uredinia medium in size, occasionally coalescent, chlorotic areas may be present.

4 ... *Very susceptible*—Uredinia large, numerous and confluent ; hypersensitiveness absent.

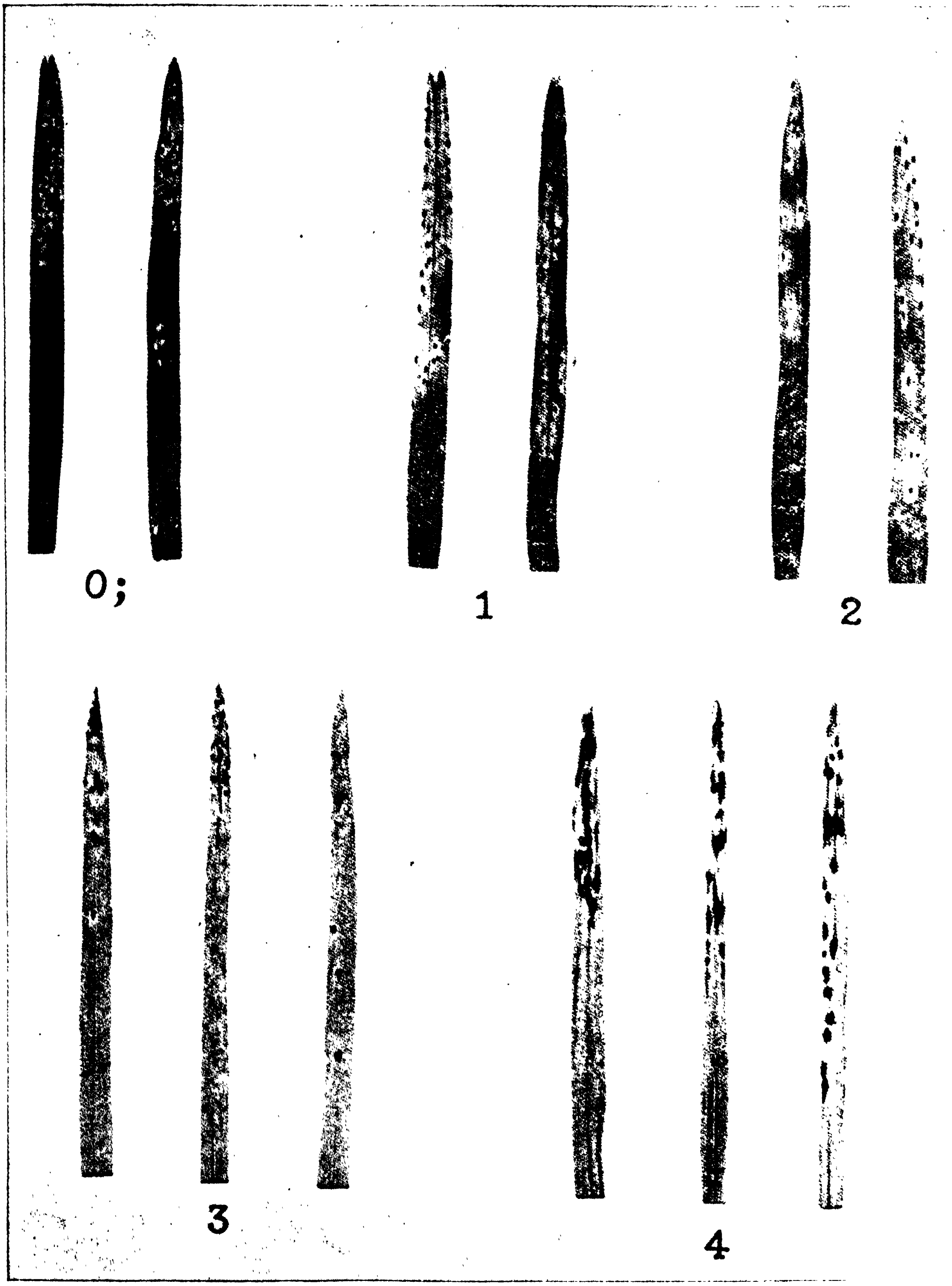
+ and — signs are used to indicate respectively, more vigorous and weaker infection than normal.

c ... represents general chlorosis.

n ... stands for necrosis.

; ... indicates necrotic flecks.

The common types of infection are illustrated in Plate V.



Types of infection as explained in the text, page 14. All leaves ($\times 1\frac{1}{3}$)

II. RUST COLLECTIONS AND THEIR ANALYSIS

The method of inoculation and procedure adopted for the selection of isolations likely to lead to the identification of different races have been described in Part One.

Details regarding the composition of thirty-five samples collected during 1930-32, wherein four different races (15, 40, 42 and 75) were found, have been supplied in an earlier article [Mehta, 1933]. Since then, 551 collections of this rust in the uredostage, including 145 from hills and hilly tracts, have been fully analysed. In all, six physiologic races, including the four referred to above, have been found. The new races are 21 and 24, both of which are rather rare, the former having been found only once.

Reference may here be made to race 27, which Levine [1928] found in one of the collections sent to him from Pusa in the year 1923. The other sample studied by him from Pusa gave race 15, which is fairly common in India. It might be mentioned, on the authority of Dr. Levine, that race 27 is extremely rare in U.S.A. as well as in Canada.

In the present studies, race 27 has not been met with at all, even in collections from Pusa. Evidently, it has either been lost or is exceedingly rare like race 21, as stated above. Newton and Johnson [1927] found that in Canada race 17, which was predominant from 1919-21, disappeared in the year 1925. Waterhouse [1936] pointed out the recurrence of race 45 after an absence of seven years. Hassebrauk [1937] has recorded a similar phenomenon in so far as he found race 68 in 1934 but not in the following year, although he came across three new races not included in Stakman and Levine's key.

It would be clear from Table XXVI that during the present studies also, race 24, which is rather rare, has not been met with during the last two years and race 75, which is the least prevalent out of the more common races, was not found last year. It is not possible to attribute the absence of a particular race for one or a period of years to any definite cause. Hassebrauk [1937] has explained that the qualitative and quantitative composition of the race flora of any region must be expected to undergo periodic alterations in response to varying meteorological conditions, the cultivation of predominantly resistant or susceptible varieties and the development of mutant races.

Collections from hills are of special importance in this country because of the occurrence of barberries as well as oversummering of this rust in the uredostage in those areas. For these reasons, more than 25 per cent collections were selected for study from hills and hilly tracts, notwithstanding the fact that the acreage under wheat and barley in those areas is less than 5 per cent of the total.

Names of places, wherefrom collections of black stem-rust of wheat were obtained during the last five years as well as the composition of samples from each locality are shown in Tables I-VIII.

In Table IX, details have been supplied of collections made from barley and three wild grasses (*Bromus patulus*, *Brachypodium sylvaticum* and *Avena fatua*), on each of which black stem-rust of wheat has been found to occur occasionally.

It may be pointed out, that no typical sample of the aecidial stage of this rust was found on *Berberis* during the present studies.

Barclay [1887] reported the occurrence of *P. graminis* Pers. on *Berberis aristata* in the Simla hills.

Aecidia of *P. graminis* Pers. have also been recorded by Butler and Bisby [1931] on *B. aristata* and three other species of this genus.

Arthur and Cummins [1933] identified rust on another species of *Berberis* from Kashmir as *P. graminis* Pers.

There is no experimental proof of the connection of any of the above specimens with the black rust of cereals. In fact, there is no case on record, with necessary data, of an outbreak of this rust in India on cereal crops in plains or even the hills, which could be connected with infected bushes of *Berberis*. The commonest aecidia on barberries in this country belong to *Aecidium montanum* Butl. The rôle of Indian barberries will be fully discussed in Section II.

TABLE I

Physiologic Races of Puccinia graminis tritici *met with in sixty-one samples of black rust of wheat from the Punjab, Kashmir, N.-W. F. Province and Baluchistan. (Collections from altitudes* of nearly 3,000-10,000 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab										
1. Narkunda ...	1	15, 75	1	15, 75	1	42	1	15, 42	1	15
2. Mattiana ...	1	40, 75	1	15, 75	1	15, 24, 42	1	15	1	42
3. Theog ...	...	...	...	...	1	15, 42	...	...	...	...
4. Fagu	...	..	...	...	...	...	1	40	1	15, 42
5. Kufri	...	...	...	...	1	42	1	15	...	...
6. Simla	3	15, 40, 42, 75	2	15, 40	1	15, 42, 75	1	15	1	40, 42

* Information regarding the approximate altitudes of the places mentioned in this table given in the Appendix.

TABLE I—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab—contd.										
7. Kotgarh ...	...	...	...	...	..	...	1	42	...	...
8. Kandaghat ...	...	...	...	...	1	24, 42	1	40, 42	...	...
9. Solon	...	...	...	...	1	24	...	...	...	...
10. Kasauli ...	...	...	...	...	...	...	1	40, 42	...	...
11. Barog	...	...	1	15, 40	...	...	...	...	...	...
12. Dharampore ...	1	15, 40	...	...	1	42	1	42	...	...
13. Lahaul ...	...	...	1	24, 42	...	...	...	...	...	...
14. Manali	...	...	...	...	...	...	1	42	...	...
15. Palampore ...	...	...	...	...	...	...	...	...	1	42
16. Kangra ...	4	15, 40, 42	...	...	...	...	...	...	...	...
17. Murree ...	...	...	...	...	...	...	1	15, 42	...	...
18. Company Bagh ...	...	...	...	...	...	...	1	15, 42	...	...
19. Dalhousie ...	...	...	...	...	...	...	1	42	...	...
Kashmir										
20. Pahalgam ...	...	...	...	...	...	...	1	15, 42	...	...
21. Bawa Rishi ...	...	...	...	...	...	...	1	15	...	...
22. Banihal ...	...	...	...	...	...	...	1	15, 42	...	...
23. Kangan ...	...	...	...	...	...	...	1	15, 40, 42	...	...
24. Batote ...	...	...	...	...	...	...	1	15, 42	1	15, 42
25. Srinagar ...	...	...	1	15, 40	...	...	1	15, 42	...	...
26. Ikhrajpura ...	...	...	...	...	...	...	1	15, 40	...	...
27. Baramula ...	...	...	...	...	...	...	1	40, 42	...	...
28. Pattan ...	...	...	...	...	...	...	1	15, 40, 42	...	...
29. Avantipur ...	...	...	..	...	...	...	1	15	...	...
30. Shalabag ...	...	...	...	...	1	15	...	...	...	..
31. Sopore ...	...	...	...	...	1	15, 42	...	...	...	...
N.-W. F. Province										
32. Abbotabad ...	...	..	..	...	...	...	1	42	...	...
33. Manshera ...	...	...	...	...	...	...	1	42	1	15
Baluchistan										
34. Quetta ...	1	15	...	...	...	...	...	...	1	15, 42
	11	15, 40, 42, 75	7	15, 24, 40, 42, 75	10	15, 24, 42, 75	25	15, 40, 42	8	15, 40, 42

Total number of collections ... 61

Races met with ... ... 15, 24, 40, 42 and 75

TABLE II

Physiologic Races of Puccinia graminis tritici *met with in seventy-six samples of black rust of wheat from the Punjab, N.-W. F. Province, Sind and Delhi. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab										
1. Koti	1	15	...	..	...	...	1	15, 42	...	..
2. Koti-Kalka ...	...	...	...	...	..	...	...	...	1	42
3. Kalka ...	1	40, 42	...	...	1	42	...	...	...	...
4. Ambala ...	1	15	...	...	1	42	...	...	1	42
5. Karnal ..	5	15, 42, 75	6	15, 40, 75	2	40, 42	4	15, 40, 42	1	15, 42
6. Rupar ...	...	..	...	...	1	42	...	...	..	...
7. Lahore ...	1	15	...	...	1	42	1	40, 42	...	...
8. Lyallpur ...	3	15	1	21, 42	1	42	3	40, 42	4	40,42
9. Sheikhupura ...	..	...	...	...	...	..	1	15	...	...
10. Hoshiarpur ...	2	40, 42	2	40, 75	1	15	...	...	...	...
11. Una	1	15, 40	...	...	...	...	..	...	...	...
12. Gurdaspur ...	...	...	1	40, 75	1	15, 40	1	15	..	...
13. Pathankote ...	1	15	...	...	1	75	...	...	...	...
14. Khanewal ...	...	...	1	15	...	...	...	...	...	...
15. Jullundur ...	1	40	...	...	1	42	...	...	1	42
16. Bharakao ...	1	15	...	...	...	...	...	...	...	...
17. Wazirabad ...	1	15, 42	...	...	...	...	...	...	...	...
18. Montgomery ...	1	15	..	...	...	...	...	...		...
19. Multan ...	...	...	...	...	...	...	1	42	..	...
20. Rawalpindi ...	...	...	1	40	...	...	...	...	...	...
21. Lodhran ...	...	...	...	...	...	...	1	42	...	...

TABLE II—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
N.-W. F. Province										
22. Tarnab	...	...	...	...	1	42	...	...	...	...
23. Mardan	...	..	1	15, 40, 42	...	...	...	...	...	..
Sind										
24. Sakrand	2	15	1	15	...	...	3	15, 40, 42	...	...
Delhi										
25. Delhi	1	15, 24, 42, 75	1	15, 75	1	42	1	40	...	...
	23	15, 24, 40, 42, 75	15	15, 21, 40, 42, 75	13	15, 40, 42, 75	17	15, 40, 42	8	15, 40, 42

Total number of collections 76
Races met with ... ... 15, 21, 24, 40, 42 and 75

TABLE III

Physiologic Races of Puccinia graminis tritici *met with in twenty-six samples of black rust of wheat from the United Provinces and Nepal. (Collections from altitudes* of nearly 3,000-7,500 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Kumaon Hills										
1. Almora	1	40, 42	...	...	...	...	..	...	...	...
2. Muktesar ...	...	...	1	15	...	...	...	...	...	...

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

TABLE III—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
***Kumaon Hills*—contd.**										
3. Someshwar ...	1	42	...	...	...	...	...	...	...	...
4. Bageshwar ...	1	42	...	..	...	...	...	...	..	...
5. Tarikhet	1	42	2	15, 40	...	...	...	...	...	...
6. Bhimtal	...	...	1	15, 40	...	...	..	...	..	...
7. Champawat ...	...	...	1	15	...	...	...	...	...	...
8. Jeolikote	...	..	...	...	1	42	...	..	...	...
9. Eastern Kumaon ...	...	...	1	15, 40	...	...	...	...	...	...
Siwalik Range										
10. Chakrata ...	1	15, 42	...	...	...	...	...	...	...	...
11. Lansdowne ...	...	...	1	15	...	..	...	...	...	...
Nepal										
12. Asurkot	..	...	...	...	..	...	1	42	.	...
13. Nawakot	...	...	...	..	...	...	1	15, 42	..	...
14. Khilchi	...	...	...	...	..	...	1	15	...	...
15. Tansing	...	...	...	..	...	...	1	42	...	..
16. Piuthan	...	...	..	...	1	75	1	15, 42	1	15, 40
17. Balkot	...	...	...	...	...	...	1	42	...	...
18. Riri	...	..	...	..	..	...	1	42	1	40, 42
19. Wangla	...	...	...	...	...	...	...	...	1	42
20. Malunga	...	...	...	...	...	...	...	...	1	42
21. Galkot	...	...	...	...	...	...	...	...	1	42
	5	**15, 40, 42**	**7**	**15, 40**	**2**	**42, 75**	**7**	**15, 42**	**5**	**15, 40, 42**

Total number of collections 26
Races met with ... ... 15, 40, 42 and 75

TABLE IV

Physiologic Races of Puccinia graminis tritici *met with in sixty-nine samples of black rust of wheat from the United Provinces. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
1. Dogadda	...	..	1	15, 75	1	15	...	...	...	...
2. Lower Kumaon ...	1	40, 42	...	...	...	...	...	...	...	...
3. Haldwani... ...	...	...	1	40	1	42	...	...	..	..
4. Nepalganj ...	1	40	1	15	...	..	...	...	...	...
5. Mailani	...	...	1	15	...	...	...	...	...	..
6. Pilibhit	1	15	..	..	...	...	1	42	...	...
7. Bareilly	1	15	1	15	...	...	1	42	...	...
8. Chandausi ..	1	42	...	...	...	...	...	...	...	...
9. Nautanwa ...	1	40	1	15	...	...	..	...	1	15, 42
10. Gainsari	...	...	...	...	...	...	1	42	...	..
11. Dehra Dun ...	..	..	1	15	...	...	1	40, 42	...	...
12. Gorakhpur ...	1	40	...	...	1	42	3	15, 42, 75	1	15
13. Gonda	...	...	...	..	...	...	1	42	...	...
14. Barabanki ...	1	15, 40, 42	...	..	...	...	...	...	...	..
15. Lucknow ...	1	42	1	15	...	...	...	...	...	...
16. Fyzabad	1	40	1	15, 40	2	40, 75	1	42	1	42
17. Shahjahanpur ...	...	..	1	15	...	...	1	15, 42	..	.
18. Khalilabad ...	...	...	...	..	...	...	1	42	...	...
19. Cawnpore ...	...	...	1	40	3	15, 40	...	...	1	42
20. Allahabad ...	1	75	1	15, 40	2	42	...	...	...	...
21. Benares	1	15, 40	...	...	1	42	...	...	1	15, 42
22. Etawah	...	...	...	...	1	42	...	...	...	...
23. Agra	3	15, 42	2	15, 40	3	15, 40, 42	3	15, 42	2	42
24. Firozabad ...	...	...	...	...	1	40, 42	...	...	...	...
25. Jhansi	...	..	1	15, 40	2	15, 42	...	...	...	...
	15	15, 40, 42, 75	15	15, 40, 75	18	15, 40, 42, 75	14	15, 40, 42, 75	7	15, 42

Total number of collections 69
Races met with ... ... 15, 40, 42 and 75

TABLE V

Physiologic Races of Puccinia graminis tritici *met with in twenty-five samples of black rust of wheat from Bihar, Bengal and Assam. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bihar										
1. Raxaul	...	...	1	15	...	...	...	...	...	...
2. Jogbani	1	15, 42	...	...	...	...	...	...	...	...
3. Pusa	3	40, 42, 75	2	15, 75	2	15, 40	1	40	1	15
4. Patna	1	15, 75	...	...	1	40	...	...	...	...
5. Sabour	8	15, 40, 42	1	40	3	40, 42, 75	...	...	...	...
Bengal										
6. Nimtita	1	15, 40, 42	...	...	1	42	...	...	...	...
7. Malda	1	40, 42	...	...	1	40	...	...	...	...
Assam										
8. Dhubri	...	...	...	...	...	...	...	...	1	42
	10	15, 40, 42, 75	4	15, 40, 75	8	15, 40, 42, 75	1	40	2	15, 42

Total number of collections 25

Races met with ... ... 15, 40, 42 and 75

TABLE VI

Physiologic Races of Puccinia graminis tritici *met with in forty-eight samples of black rust of wheat from Rajputana, Central India and Central Provinces. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Rajputana										
1. Bharatpur ...	...	...	..	...	1	24, 42	...	...	...	...
2. Jaipur	...	...	...	...	1	42	...	...	1	42
3. Ajmer	1	40, 42	1	42	...	...	...	...	...	...
4. Jodhpur	...	...	...	...	2	24, 42	...	...	...	...
5. Bundi	...	...	...	...	1	24, 42	...	...	...	...
Central India										
6. Dhamnod ...	1	40	...	...	...	...	...	...	...	...
7. Datia	...	...	1	15	1	40	...	...	...	...
8. Indore	...	...	...	...	5	15, 40, 42	5	15, 40, 42, 75	3	42
9. Bhopal	...	...	...	...	...	...	...	...	1	42
Central Provinces										
10. Saugor	...	...	...	...	...	...	1	42	3	40, 42
11. Jubbulpore-Kheri ...	...	...	1	15, 42	2	42	2	40, 42	2	42
12. Powarkhera ...	...	...	...	...	1	42	1	15, 42	2	42
13. Raipur	...	...	...	...	2	15, 42	1	42	1	42
14. Nagpur	...	...	...	...	2	42	...	...	...	...
15. Kuksi	...	...	1	40	...	...	...	...	...	...
16. Khandwa... ...	1	15	...	...	...	...	...	..	...	...
	3	15, 40, 42	4	15, 40, 42	18	15, 24, 40, 42	10	15, 40, 42, 75	13	40, 42

Total number of collections 48

Races met with ... ... 15, 24, 40, 42 and 75

TABLE VII

Physiologic Races of Puccinia graminis tritici *met with in thirty-eight samples of black rust of wheat from Bombay-Deccan, Madras and Mysore. (Collections from altitudes* of nearly 2,500-7,000 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bombay-Deccan										
1. Old Mahableshwar ...	...	...	...	...	1	15, 42	1	42	1	40
2. Mahableshwar ...	...	..	...	...	1	15	1	15	1	42
3. Wagamba ...	...	...	1	15	...	...	...	...	...	..
4. Babulana ...	2	40, 42, 75	...	...	...	...	...	...	1	15, 42
5. Bej	...	...	...	...	...	...	...	...	1	42
6. Babkhera... ...	1	40, 42	...	...	...	...	...	...	...	...
7. Visapur	...	...	...	...	..	...	...	...	1	15
8. Wani	..	..	...	...	...	...	...	...	1	42
9. Singarwari ...	1	15, 42	...	..	...	...	...	...	...	...
10. Pohali	1	42	...	...	...	...	...	...	...	...
11. Mulher	...	...	...	...	...	...	1	42	...	...
12. Sambarsari ...	...	...	...	...	...	...	1	42	...	...
13. Kharad	...	...	...	...	1	15, 42	...	...	...	...
14 Western Ghats ...	1	75	...	...	...	...	...	...	...	...
15. Chinchali ...	...	...	1	40, 42	1	40	...	...	..	...
16. Dangs	1	15	...	...	...	...	1	42	...	...
17. Anantapur ...	...	...	...	...	...	...	...	...	1	42
Madras										
18. Thambatti ...	...	...	..	..	...	...	1	15	...	...
19. Kilkavati ...	..	...	...	...	...	...	1	40, 42	...	...
20. Ketti	...	...	...	...	...	...	1	15	...	..
21. Ellenhatti ...	...	...	1	15	...	...	...	...	...	...
22. Hoobathalai ...	...	...	1	40	...	...	...	...	...	...
23. Kallakorai ...	...	...	...	...	...	...	...	...	2	15
24. Thoddanni ...	...	...	...	...	...	...	...	...	1	15
25. Pottangi	...	...	2	15, 40, 42	1	42	1	42	...	...
Mysore										
26. Hebbal (Bangalore) ...	...	...	1	42	...	...	...	...	...	...
	7	15, 40, 42, 75	7	15, 40, 42	5	15, 40, 42	9	15, 40, 42	10	15, 40, 42

Total number of collections 38

Races met with ... ... 15, 40, 42 and 75

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

TABLE VIII

Physiologic Races of Puccinia graminis tritici *met with in 170 samples of black rust of wheat from Baroda State, Kathiawar, Bombay-Deccan, Hyderabad-Deccan, Mysore and Madras. (Collections from the plains and up to altitudes of nearly 2,500 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Baroda State										
1. Baroda	2	15, 40, 42	1	40	2	42	3	40, 42	...	...
2. Jagudan	...	..	1	15	1	42	2	42	...	...
3. Amreli	...	..	...	...	3	15, 42	1	40, 42	...	...
4. Pipal-Va	...	...	...	...	...	...	.	.	1	42
5. Mota-anakadia ...	...	...	...	...	...	...	...	...	1	42
6. Amritpur ...	..	...	...	...	...	...	...	..	1	42
Kathiawar										
7. Junagad	1	15	...	...	...	...	..	...	1	42
8. Dhamlej	...	...	...	...	...	...	...	..	1	42
9. Patan	...	...	...	...	...	...	...	...	1	42
10. Rajkot	...	...	...	...	...	...	...	..	1	42
Bombay-Deccan										
11. Dohad	1	15	...	...	1	40	2	42	...	...
12. Broach	...	...	...	...	...	..	1	42	1	42
13. Kalyan	1	15, 42	...	...	1	42	1	40	...	...
14. Niphad	5	15, 40, 42	2	40, 42	1	40	4	15, 40, 42	2	42
15. Nasik	...	...	...	...	...	...	...	...	2	42
16. Dindori	...	...	...	...	..	...	..	.	1	42
17. Vaishad	...	...	...	...	...	...	..	...	1	42
18. Sinnar	...	...	...	...	...	...	...	...	1	42
19. Malechawadi ...	...	...	.	...	...	...	...	..	1	42
20. Manmad	...	...	...	..	1	42	...	...	...	...

TABLE VIII—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bombay-Deccan—contd.										
21. Khandesh ...	...	...	...	...	..	..	...	...	1	42
22. Ashalali	...	...	...	...	...	...	...	...	2	42
23. Poona	17	15, 42	2	15, 40	12	24, 42	6	15, 42	3	40, 42
24. Shirwal	...	...	...	...	...	...	1	40	1	42
25. Saswad and Purandhar	...	..	...	...	..	...	...	...	1	42
26. Vankia	...	...	...	...	...	...	...	...	1	42
27. Vadarhatti ...	...	..	1	42	...	.	...	...	...	...
28. Arbhavi-Mosagappi ...	...	..	...	...	...	...	1	42	...	...
29. Dharwar	2	40	...	...	1	40, 42	1	42	3	15, 42
Hyderabad-Deccan										
30. Parbhani ..	1	15	1	40	6	40, 42	1	42	4	40, 42
31. Himayatsagar ...	3	15, 40, 42	2	24, 40, 42	4	40, 42, 75	...	...	2	15, 42
32. Islampur	1	15	..	..	..	..	..	..	..	..
Mysore State										
33. Mandya	...	...	1	42	8	15, 40, 42	4	42	..	..
34. Chitaldroog ...	...	...	...	...	2	15, 42	1	42	1	42
35. Hiriyur-Maradihalli ..	1	40, 42	1	15	..	..	1	42	1	40, 42
36. Sakripatnam ..	..	...	...	...	...	...	...	...	1	42
Madras Presidency										
37. Coimbatore ...	3	15, 40	1	40	...	...	...	...	2	15
38. Hagari	...	..	1	42	.	...	2	40, 42	1	42
39. Guntur	...	...	1	40	...	...	...	...	...	..
40. Kamaripatti ...	...	...	1	40	...	...	...	...	...	...
41. Basuli-Kotpad ...	...	...	1	40	...	...	...	...	...	...
	38	15, 40, 42	17	15, 24, 40, 42	43	15, 24, 40, 42, 75	32	15, 40, 42	40	15, 40, 42

Total number of collections 170

Races met with ... ... 15, 24, 40, 42 and 75

TABLE IX

Physiologic Races† *of* Puccinia graminis tritici *met with in thirty-two samples of black rust of barley and six samples of black rust of grasses collected during 1932-37 from different parts of India (hills,* hilly tracts and plains)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Hills				*Barley*						
1. Narkunda (Punjab) ...	...	...	...	...	1	15	...	...	...	...
2. Mattiana ,, ...	...	...	...	...	1	42	...	...	...	...
3. Simla ,, ...	...	...	1	15	1	42	1	42	1	42
4. Kasauli ,, ...	...	...	...	...	...	..	1	42	..	...
5. Solon ,, ...	...	...	...	...	...	...	1	42	...	...
6. Martand (Kashmir) ...	...	...	...	...	...	...	1	15	...	...
7. Chapnari ,, ...	...	...	...	...	...	...	1	15	...	...
8. Batote ,, ...	...	...	...	...	...	...	...	..	1	15
9. Mount Abu (Rajputana)	..	..	...	...	...	...	...	...	1	42
10. Gokul (Bombay) ...	...	...	...	...	...	...	...	...	1	42
11. Kilkavati (Madras) ...	...	...	...	...	...	...	1	42	...	..
Plains										
12. Karnal (Punjab) ...	...	...	...	...	1	40, 42	1	15, 42	...	..
13. Lyallpur ,, ...	...	...	...	...	...	...	...	...	1	42
14. Delhi (Delhi) ...	...	...	...	..	1	42	1	15, 42	...	..
15. Nautanwa (U. P.) ...	...	...	...	...	...	...	1	42	...	...
16. Gainsari ,, ...	...	...	...	...	...	...	...	..	1	15, 42
17. Gorakhpur ,, ...	..	...	...	...	1	42	...	...	...	...
18. Benares ,, ...	...	...	...	...	...	...	...	...	1	40, 42
19. Agra ,, ...	...	...	...	...	...	...	...	...	1	42
20. Pusa (Bihar) ...	...	...	1	15	2	15, 40	1	15	...	...

† As recorded in the last article [Mehta, 1933], races 15 and 42 were also found in an earlier collection from *Bromus patulus* and race 75 on barley. So far thirty-three collections from barley and seven from grasses have been analysed.

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

TABLE IX—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
				Barley—contd.						
Plains—contd.										
21. Indore (C. I.) ...	...	...	...	...	...	...	2	40, 42	...	...
22. Poona (Bombay) ...	...	...	...	...	...	...	1	40	...	...
23. Coimbatore (Madras)	...	...	...	...	...	...	...	...	1	42
				*Grasses**						
Hills										
24. Mattiana (Punjab) ...	...	...	1	15	...	...	...	...	...	...
25. Simla „ .	1	40, 42	1	15	...	...	...	...	...	...
26. Banihal (Kashmir) ...	...	...	...	...	...	...	1	40, 42	...	...
27. Pahalgam „ ...	...	...	...	...	...	...	...	...	1	15
28. Naukuchia (U. P.) ...	1	40	...	...	...	...	..	...	...	..
	2	40, 42	4	15	8	15, 40, 42	14	15, 40, 42	10	15, 40, 42

Total number of collections 38
Races met with ... ... 15, 40 and 42

*Collections No. 24, 26 and 27 were obtained from *Bromus patulus* ; No. 25 from *Brachypodium sylvaticum* and No. 28 from *Avena fatua.*

12. SINGLE SPORE CULTURES

A single spore culture of each of the six physiologic races found in this country has been maintained in the uredostage. One of the cultures is nearly seven years old and had completed its hundredth generation by the end of July 1938. All these cultures are tested on differential hosts at least twice every year, in order to see if any mutation has taken place, as well as to study their range of infection from time to time. An account of the history of each of these cultures is given in Table X. So far, no case of mutation has been observed as far as the pathogenicity of each of the races is concerned. The range of infection of each of the races is shown in Tabe XI. For the sake of comparison, the " mean of reaction of differential varieties " as recorded in the latest key of Stakman and Levine are given in Table XII,

TABLE X

History of single spore cultures of Puccinia graminis tritici

Race	Name of station and original host	Stock collection or isolation	Started in	Age in generations	No. of tests made
15	Ketti-Local ...	Stock ...	March, 1934 ...	61	10
21	Lyallpur-C518 ...	Ver (2)-Ko(4) ...	June, 1935 ...	46	6
24	Himayatsagar-Bansi ...	Ver (2)-Khp (2) ...	April, 1935 ...	49	7
40	Poona-Pusa 4 ...	Enk (1) ...	May, 1932 ...	93	13
42	Poona-Pusa 4 ...	Khp (4) ...	July, 1932 ...	91	12
75	Simla-Local ...	Stock ...	Dec., 1931 ...	100	12

TABLE XI

Range of infection produced by single spore cultures of the different physiologic races of P. graminis tritici *met with in India so far*

Race	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli
15	4	4	4	4	4	4	4	4	4	4	4	0 ;-2
21	4	4	0 ;	4	4	4	4	4	4	0 ;-1	0 ;-2	0 ;-2
24	4	4	0 ;	0 ;	4	4	4	4	4	4	0 ;-2	0 ;-2*
40	3-4	4	4	4	3-4	4	4	4	4	0 ;-1	3-4	0 ;-1
42	3-4	4	0 ;	0 ;	4	4	4	4	4	4	0 ;-2	3-4c
75	4	4	0 ;	0 ;	4	4	4	4	4	0 ;-1	0 ;-2	0 ;-2

* In the case of Race 24, Khapli has occasionally shown susceptible type of infection 3-4 (?) also. The resistant and susceptible types of pustules have been isolated and grown on Khapli under two different ranges of temperature. This culture is being studied further in order to make sure if it is a different race with "X" type infection on Khapli.

TABLE XII

Mean reaction of differential varieties to Physiologic Races of P. graminis tritici *occurring in India, as recorded in Stakman and Levine's key* isused in the year 1935*

Race	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli
15	4	4–	4=	3++	4=	4=	4=	3++	3++	3++	4+	1=
21	4	4	0	3++	4–	4–	4–	4=	3++	1=	0;	1=
24	4	4=	0;	2=	4=	4=	4=	3++	3+	3+	1=	0;
40	4+	4+	4	4+	4+	4+	4	4=	4	0;	4=	1=
42	4	4	0	0;	4+	4	4	4	4	4=	2=	4c
75	4	3+	2+	0;	3+	3+	3+	4–	3+	1	0;	1

* A cyclostyled copy of the key was kindly supplied by the authors to the writer, on request.

18. MIXTURES OF PHYSIOLOGIC RACES IN NATURE

Out of a total of 586 collections of *P. graminis tritici* from different hosts. obtained during the last seven years, 163 were mixtures of two races or more. The remaining 423 collections yielded one race each. Details regarding the composition of 163 collections that proved to be mixtures are given in Table XIII.

Series of inoculations leading to the identification of all the five races occurring alone are shown in Tables XIV—XVIII. Race 21 was found only once and that too mixed with Race 42. Series of inoculations leading to the identification of each of the six races in representative combinations, as found in nature, are shown in Tables XIX—XXIII.

General information and summary of data concerning the analysis of 586 collections of *P. graminis tritici* are given in Table XXIV.

Table XIII

Composition of 163 collections of Puccinia graminis tritici *that were found to be mixtures*

Number of Combinations	Races	Total number of collections
1	15 and 40	22
2	15 and 42	55
3	15 and 75	8
4	21 and 42	1
5	24 and 42	6
6	40 and 42	51
7	40 and 75	4
8	42 and 75	4
9	15, 24 and 42	1
10	15, 40 and 42	5
11	15, 40 and 75	1
12	15, 42 and 75	1
13	24, 40 and 42	1
14	40, 42 and 75	2
15	15, 24, 42 and 75	1

Table XIV

Series of inoculations leading to the identification of Race 15 of Puccinia graminis tritici

Place and year of collections :—Nepalganj (United Provinces) ; 1933-34
Host —Wheat "Local"

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	5/6 (4)	6/6 (4)	3/5 (4)	6/6 (4)	5/5 (4)	6/6 (4)	5/5 (4)	6/6 (4)	7/7 (4)	6/6 (4)	5/5 (4)	10/10 (2=)	15
Enk (4)	2/5 (4)	5/5 (3-4)	3/5 (4)	3/5 (4)	4/5 (4)	6/7 (4)	4/4 (4)	7/7 (4)	4/5 (4)	7/7 (4)	5/6 (4)	4/5 (2)	15

The numerator and denominator represent respectively the number of leaves infected and inoculated. The figures in brackets indicate the type of infection.

TABLE XV

Series of inoculations leading to the identification of Race 24 of Puccinia graminis tritici

Place and year of collection :—*Solon* (*Punjab*) ; *1934-35*

Host :—*Wheat* " *Local* "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	5/5 (4)	4/4 (4)	0/5 (0 ;)	0/5 (0 ;)	5/5 (4)	3/5 (4)	4/5 (4)	5/5 (4)	5/5 (4)	4/4 (4)	3/3 (2)	4/4 (2)	24
Enk (4)	5/5 (4)	5/5 (4)	0/3 (0 ;)	0/5 (0 ;)	3/4 (4)	3/3 (4)	4/4 (4)	5/5 (4)	5/5 (4)	4/4 (4)	3/3 (2+)	4/4 (2+)	24

TABLE XVI

Series of inoculations leading to the identification of Race 40 of Puccinia graminis tritici

Place and year of collection :—*Kuksi* (*Central Provinces*) ; *1933-34*

Host :—*Wheat* " *Local* "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	5/7 (4)	5/7 (4)	7/7 (4)	9/9 (4)	4/5 (4)	7/7 (4)	8/9 (4)	5/7 (4)	7/7 (4)	5/6 (1)	7/8 (4)	3*/10 (0-1)	40
Enk (1)	5/5 (4)	7/8 (4)	7/7 (4)	6/6 (4)	7/7 (4)	6/6 (4)	5/5 (4)	6/6 (4)	6/6 (4)	5/5 (1)	5/5 (4)	7/7 (1)	40

* Other leaves showed (0 ;) only.

TABLE XVII

Series of inoculations leading to the identification of Race 42 of Puccinia graminis tritici

Place and year of collection :—Dharwar (Bombay-Deccan) ; 1936-37

Host :—Wheat " St. No. 808 "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	6/6 (4)	5/5 (4)	0/6 (0 ;)	0/5 (0 ;)	6/6 (4)	6/6 (4)	5/5 (4)	5/5 (4)	5/5 (4)	4/4 (4)	3/3 (2)	5/5 (4c)	42
Khp (4c)	6/6 (4)	5/5 (4)	0/4 (0 ;)	0/6 (0 ;)	6/6 (4)	5/5 (4)	5/5 (4)	4/4 (4)	5/5 (4)	6/6 (4)	4/4 (2)	4/4 (4c)	42

TABLE XVIII

Series of inoculations leading to the identification of Race 75 of Puccinia graminis tritici

Place and year of collection :—Sabour (Bihar) ; 1934-35

Host :—Wheat " Pusa 4 "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	5/5 (4)	5/5 (4)	0/5 (0 ;)	0/3 (0 ;)	3/3 (4)	3/5 (4)	5/5 (4)	5/5 (4)	5/5 (4)	4/5 (1)	4/4 (2)	4/4 (1-2)	75
Enk (1)	4/4 (4)	4/4 (4)	0/5 (0 ;)	0/4 (0 ;)	4/5 (4)	4/4 (4)	5/5 (4)	4/4 (4)	5/5 (4)	3/3 (1)	3/3 (2)	3/3 (1-2)	75

Table XIX

Series of inoculations leading to the identification of Races 15 and 75 of Puccinia graminis tritici

Place and year of collection :—Delhi ; 1933-34
Host :—Wheat " Local "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	7/7 (4)	5/5 (4)	8/8 (4)	8/8 (4)	8/8 (4)	10/10 (4)	7/7 (4)	6/6 (4)	8/8 (4)	6/6 (1 & 4)	5/5 (3-4)	8/5 (1-2)	
Enk (4)	8/5 (3-4)	5/8 (4)	3/5 (4)	6/9 (4)	2/5 (4)	3/5 (4)	2/4 (4)	2/4 (4)	5/6 (4)	5/5 (4)	5/6 (4)	5/5 (1-2)	15
Enk (1)	4/6 (4)	8/5 (4)	0/5 (0 ;)	0/4 (0 ;)	4/4 (4)	5/5 (4)	5/5 (4)	6/6 (4)	5/6 (4)	8/4 (1=)	8/5 (2=)	4/4 (1-2)	75

Table XX

Series of inoculations leading to the identification of Races 21 and 42 of* Puccinia graminis tritici

Place and year of collection :—Lyallpur (Punjab) ; 1933-34
Host :—Wheat " C. 581 "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	6/6 (4)	6/6 (4)	0/6 (0 ;)	8/8 (4)	6/6 (4)	8/8 (4)	8/8 (4)	6/6 (4)	9/9 (4)	3/4 (4, 1)	6/6 (2 ?)	5/5 (3c,2?)	
Ver (2 ?)				7/7 (4)							5/5 (2)		
Ver (2 ?)—Ko (4) ...	4/6 (4)	6/6 (4)	0/6 (0 ;)	5/5 (4)	4/5 (4)	5/5 (4)	5/6 (4)	6/6 (4)	5/5 (4)	5/5 (1=)	5/5 (2)	5/5 (2)	21
Enk (4)	6/6 (4)	6/6 (4)	0/5 (0 ;)	0/5 (0 ;)	6/6 (4)	7/7 (4)	7/7 (4)	6/6 (4)	6/6 (4)	4/4 (4)	1†/5 (2, 0 ;)	5/5 (3-4c)	42

*So far, Race 21 has not been met with in any other collection.
†4 leaves showed (0 ;)

Table XXI

Series of inoculations leading to the identification of Races 24 and 42 of Puccinia graminis tritici

Place and year of collection :—Bharatpur (Rajputana) ; 1934-35
Host :—Wheat " Pb. 9D"

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	5/5 (4)	5/5 (4)	0/5 (0 ;)	0/5 (0 ;)	5/5 (4)	4/4 (4)	5/5 (4)	5/5 (4)	7/7 (4)	3/3 (4)	0/3 (0 ;)	3/3 (2, 4c)	
Khp (4c)	5/5 (4)	5/5 (4)	0/5 (0 ;)	0/5 (0 ;)	5/5 (4)	5/5 (4)	5/5 (4)	5/5 (4)	5/5 (4)	4/4 (4)	4/4 (2=)	4/4 (4c)	42
Khp (2)	5/5 (4)	5/5 (4)	0/5 (0 ;)	0/5 (0 ;)	4/4 (4)	5/6 (4)	5/5 (4)	4/4 (4)	5/5 (4)	3/4 (4)	3/3 (2)	3/3 (2)	24

Table XXII

Series of inoculations leading to the identification of Races 40 and 75 of Puccinia graminis tritici

Place and year of collection :—Gurdaspur (Punjab) ; 1933-34
Host :—Wheat " Pb. 8A "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	4/7 (4)	4/9 (4)	8/8 (3+)	7/7 (4)	8/8 (4)	7/8 (4)	8/8 (4)	8/8 (4)	3/5 (4)	6/6 (1)	5/6 (1, 3-4)	3/5 (1)	
Ver (4) ...	5/5 (4)	5/5 (4)	5/5 (4)	7/7 (4)	8/8 (4)	5/6 (4)	6/7 (4)	4/5 (3-4)	8/8 (3-4)	5/5 (1)	7/7 (4)	5/5 (1—)	40
Ver (1) ...	6/6 (4)	7/7 (4)	0/5 (0 ;)	0/6 (0 ;)	6/6 (4)	5/5 (4)	7/7 (4)	7/7 (4)	8/8 (4)	6/6 (1)	5/5 (2—)	4/5 (0-2)	75

TABLE XXIII

Series of inoculations leading to the identification of Races 15, 40 and 42 of Puccinia graminis tritici

Place and year of collection :—Nimtita (Bengal); 1932-33

Host :—Wheat " Pusa 12 "

Stock or isolation	Little Club	Marquis	Reliance	Kota	Arnautka	Mindum	Spelmar	Kubanka	Acme	Einkorn	Vernal	Khapli	Race
Stock	5/6 (4)	6/6 (4)	5/7 (4)	5/5 (4)	7/8 (4)	6/6 (4)	6/6 (4)	6/6 (4)	3/3 (4)	6/6 (4, 1)	6/6 (4, 2)	6/8 (1-2, 4c)	
Khp (4) ...	5/5 (4)	7/7 (3-4c)	0/4 (0 ;)	0/4 (0 ;)	4/4 (4)	5/5 (4)	6/7 (4)	7/7 (4)	7/7 (4)	4/5 (4)	6/7 (2)	6/7 (3-4c)	42
Ko (4) ...	4/8 (4)	7/7 (4)	4/5 (4)	5/5 (4)	6/6 (4)	3/3 (4)	7/7 (4)	6/6 (4)	5/5 (4)	3/5 (1, 4)	6/6 (4)	6/6 (1-2)	
Ko (4)-Enk (4) ...	7/7 (4)	7/7 (4)	1/3 (4)	6/7 (3)	4/4 (4)	6/6 (4)	3/4 (4)	2/3 (4)	5/5 (4)	6/6 (3)	6/6 (3)	2*/7 (1—)	15
Ko (4)-Enk (1) ...	4/5 (3)	7/8 (4)	7/7 (4)	5/6 (4)	6/6 (4)	6/6 (4)	4/4 (4)	5/6 (4)	7/7 (4)	4/6 (1)	6/6 (3-4)	5/6 (1)	40

* Other leaves showed (0 ;)

Table XXIV

General information and summary of data concerning 586 collections of P. graminis tritici *that have been analysed so far*

I. Number of collections from different hosts and the races found on each :—

(i) Wheat 546	Races 15, 21, 24, 40, 42 and 75
(ii) Barley 33	Races 15, 40, 42 and 75
(iii) Grasses 7	Races 15, 40 and 42 (more samples were not available)

II. Number of collections from hills and hilly tracts :—

(i) The Punjab, U. P., Nepal, Kashmir, N.-W. F. Province and Baluchistan	113
(ii) Rajputana, Western Ghats, Eastern Ghats, Nilgiri and Palni hills, etc.	44

III. Percentage of collections from hills and hilly tracts over ... 26 (157/586)

It might be mentioned that the area under wheat and barley in the hills is less than 5 per cent of the entire acreage under these crops.

IV. Races found in the hills and hilly tracts ... ... 15, 24, 40, 42 and 75

V. Races found in plains ... ... 15, 21, 24, 40, 42 and 75

VI. Composition of collections :—

	Alone	In combination
(i) Number of collections showing race 15	122	94
(ii) Number of collections showing race 21	...	1
(iii) Number of collections showing race 24	3	9
(iv) Number of collections showing race 40	66	86
(v) Number of collections showing race 42	218	128
(vi) Number of collections showing race 75	14	21

VII. Out of 586 collections, 163 were mixtures as shown below :—

(i) Collections containing two races	151
(ii) Collections containing three races	11
(iii) Collections containing four races	1

14. Distribution and prevalence

During 1930-31, only two collections were made, consequen ly the information supplied below refers to a period of six years only (1931-37). For the sake of convenience of reference the country is divided into five areas (A, B, C, D and E), the boundaries of which have been described in Part One and illustrated in Map No. 1.

As shown in Table XXV, races 15, 40, 42 and 75 are found in all the five areas.

Race 21 has been met with only in area A, so far.

Race 24 has been found in areas A, D and E only.

With regard to their prevalence, it may be stated that :—

(i) Race 42 is the most predominant, taking the country as a whole.

(ii) Next comes Race 15, which is unfortunately the most virulent in so far as it infects eleven out of twelve differential hosts.

(iii) Race 40 is more common than the other three.

(iv) Race 75 is rather poorly represented and seems to be steadily disappearing since the year 1933. Last year (1936-37) it was not found at all.

(v) Out of the six years of study, Race 24 was not met with during three, and on the whole it is rather rare, having been found only in twelve collections.

(vi) Race 21 is the rarest and was identified only from one collection of the year 1933-34.

On completion of this study, the distribution of physiologic races in each of the five areas will be shown in a map.

The relative prevalence of all the six races is shown in Table XXVI.

TABLE XXV-A

Annual occurrence of Physiologic Races of Puccinia graminis tritici *in area A (the Punjab, Kashmir, N.-W. F. Province, Baluchistan, Sind and Delhi), during 1930-37 and the number of times each race was isolated annually*

Race	1930-31 and 1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
15	..., 3	26	15	8	26	8
21	...	...	1	...	...	...
24	...	1	1	3	...	...
40	1, 5	11	11	3	13	4
42	..., 6	11	8	22	34	13
75	1, ...	6	6	2	...	...

Table XXV-B

Annual occurrence of Physiologic Races of Puccinia graminis tritici *in area B (the United Provinces and Nepal) during 1930-37 and the number of times each race was isolated annually*

Race	1930-31 and 1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
15	..., 2	7	19	7	6	5
21	...	...	...	...	...	...
24	...	...	...	...	...	...
40	1, 3	9	10	4	1	3
42	1, 2	10	...	11	19	13
75	1, 2	1	1	2	1	...

Table XXV-C

Annual occurrence of Physiologic Races of Puccinia graminis tritici *in area C (Bihar, Bengal and Assam), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
15	1	5	3	3	1	1
21	...	...	...	...	...	...
24	...	...	...	...	...	...
40	...	4	1	5	1	...
42	...	6	...	2	...	1
75	...	8	2	1	...	...

TABLE XXV-D

Annual occurrence of Physiologic Races of Puccinia graminis tritici *in area D (Rajputana, Central India and Central Provinces), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
15	...	5	2	2	3	...
21	...	...	...	...	...	...
24	...	...	...	3	...	...
40	...	2	1	2	5	1
42	4	5	2	14	9	13
75	...	1	...	...	1	...

TABLE XXV-E

Annual occurrence of Physiologic Races of Puccinia graminis tritici *in area E (Baroda State, Kathiawar, Bombay-Deccan, Hyderabad-Deccan, Mysore and Madras), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
15	8	24	7	8	6	10
21	...	...	...	...	...	...
24	...	...	1	8	...	...
40	4	12	13	9	8	5
42	8	14	10	85	84	44
75	1	2	...	1	...	...

TABLE XXVI

Relative prevalence of Physiologic Races of Puccinia graminis tritici *in the country as a whole during 1931-37, and the number of times each race was isolated annually*

Year	Total number of collections	Races					
		15	21	24	40	42	75
1930-31* ...	35	...	...	...	2	1	2
1931-32 ...		9	...	...	12	20	3
1932-33 ...	114	67	...	1	38	46	13
1933-34 ...	80	46	1	2	36	15	9
1934-35 ...	125	28	...	9	28	84	6
1935-36 ...	129	42	...	...	28	96	2
1936-37 ...	103	24	...	...	13	84	...
TOTAL ...	586	216	1	12	152	346	35

* Only two collections were made during 1930-31, one yielded races 40 and 75, and the other 40, 42 and 75. The study of physiologic races was started in November 1932.

15. General discussion

In previous publications, the writer [Mehta, 1929; 1931, 1, 2; 1933] has observed that in this country the source of annual recurrence of rusts of wheat and barley lies in the hills, where they are able to oversummer in the uredostage.

There are several species of *Berberis*, the alternate host of black stem-rust, growing wild in the hills of India. Since the discovery of the function of spermogonia of the rust fungi by Craigie [1927], there have been several contributions on the subject of the production of new physiologic races of *P. graminis* by hybridization on *Berberis* in nature, as well as under controlled conditions [Waterhouse, 1929, 1; Stakman, Levine and Cotter, 1930; Newton, Johnson and Brown, 1930; Stakman, Hines, Cotter and Levine, 1932; Newton and Johnson 1932,; Stakman, Levine, Cotter and Hines, 1934; and Waterhouse, 1936].

The number of physiologic races of the rust under reference should have been fairly large in this country also, if all the factors concerned in the successful infection of barberries and of cereals therefrom, were at work over the greater part of the hills. As stated above, only six races have been found so far.

In order to pick up, as far as possible, all physiologic races that may be occurring in the hills, more than 25 per cent of the total number of collections selected for study come from such areas. In view of the fact that improved varieties of wheat cover less than 20 per cent of the area under that crop in India, it was felt necessary to obtain as many collections from local (un-improved, *dêsi* or indigenous) wheat and barley as possible, so that all such races to which improved varieties may be resistant, should also be picked up. Collections were obtained from 114 improved and popular varieties and 253 local wheats, that are grown extensively in different parts of the country, hills as well as plains. A host-wise list of collections from various provinces and states, the number of collections from each host and the races so far met with in each case, are given for the information of the plant breeder in Tables XXVII and XXVIII. There is nothing to suggest that a certain variety, on which so far only some of the physiologic races have been found, is necessarily resistant to others. It is quite likely that during the course of further studies, that are in progress, other races may also be found on them.

TABLE XXVII

Crosses and other varieties of wheat (indigenous and foreign) from which samples of Puccinia graminis tritici *were collected for study during 1930-37 and the Physiologic Races found on each.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
1	Manitoba × Pusa 12 ...	Sind	1	15
2	Pusa 52 × Federation ...	Punjab	1	15
3	C 409 × C 499 ...	Punjab	1	40
4	Pb 14 × Pb Local ...	Punjab	1	75
5	Pb 8A—B F 10 ...	Central India	1	40, 42 and 75
6	A R 472-A 10 ...	Hyderabad-Deccan ...	2	40 and 42
7	A R 460-B I ...	Hyderabad-Deccan ...	1	40 and 42
8	St. No. 511-608 P. Br. 519-3 ...	Hyderabad-Deccan ...	1	42
9	Osmanabad 85-6 ...	Hyderabad-Deccan ...	1	42
10	137-7	Hyderabad-Deccan ...	1	42
11	Punjab 8A ...	Punjab, Sind, United Provinces and Central India	10	15, 40, 42 and 75

TABLE XXVII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
12	Punjab 9D ...	Punjab, Rajputana and Central India	3	15, 24 and 42
13	Punjab Type 14 ...	Punjab	1	40
14	Punjab C 499 ...	Rajputana	1	24
15	Punjab C 518 ...	Punjab and United Provinces...	6	15, 21 and 42
16	Punjab C 591 ...	Punjab	1	42
17	A T 38	Sind	1	40 and 42
18	C P H 47	Sind	1	42
19	P W 1-7	Kashmir	1	15
20	Pk. H S I	Kashmir	1	15 and 42
21	Cawnpore 13 ...	United Provinces and Hyderabad-Deccan	5	15 and 42
22	Pusa 3	Mysore	1	42
23	Pusa 4	Kashmir, Punjab, United Provinces, Bihar, Baroda, Bombay-Deccan, Hyderabad-Deccan, Kathiawar, Mysore and Madras	34	15, 40, 42 and 75
24	Pusa 12	Punjab, Sind, United Provinces, Bihar, Bengal, Central India, Mysore and Madras	11	15, 40, 42 and 75
25	Pusa 52	United Provinces, Bihar, Baroda State, Bombay-Deccan, Mysore and Madras	14	15, 40 and 42
26	Pusa 80-5 ...	Punjab, United Provinces, Bihar, Baroda State, Hyderabad-Deccan and Mysore	7	15, 40 and 42
27	Pusa 100	Central Provinces	1	42
28	Pusa 101	United Provinces, Bihar, Central Provinces, Baroda State, Mysore, Bombay-Deccan and Madras	12	15, 40 and 42
29	Pusa 111	N.-W. F. Province, Punjab, United Provinces, Bihar, Baroda State, Bombay-Deccan, Hyderabad-Deccan	12	15, 40, 42 and 75
30	Pusa 112	Punjab and United Provinces...	2	15, 40 and 42

TABLE XXVII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
31	Pusa 114	Punjab, United Provinces, Bihar, Baroda State, Bombay-Deccan, Mysore and Madras	12	15, 40 and 42
32	Pusa 165	Punjab and United Provinces...	8	40 and 42
33	A 013	Central Provinces	1	42
34	A 085	Central Provinces and Hyderabad-Deccan	2	42
35	A 088	United Provinces and Central Provinces	2	15 and 42
36	A 113	United Provinces and Central Provinces	3	42
37	A 115	United Provinces, Central Provinces and Hyderabad-Deccan	5	15, 40 and 42
38	E B 33	Central Provinces	1	42
39	E B 38	Central Provinces and Hyderabad-Deccan	2	40 and 42
40	E B 276	Central Provinces	1	40 and 42
41	C P 140	Hyderabad-Deccan ...	1	40 and 42
42	J 26	Rajputana	1	42
43	N 85	Central India	1	42
44	R 14-5	Central India	1	42
45	St. No. 103 ...	Bombay-Deccan	1	40 and 42
46	Bansi 162	Bombay-Deccan and Baroda State	3	15, 40 and 42
47	Bansi 224	Bombay-Deccan	1	15
48	Bansipalli 808 ...	Bombay-Deccan	5	40 and 42
49	Bansipalli 809 ...	Bombay-Deccan	3	42
50	K K 568	Bombay-Deccan	4	40 and 42
51	Kesar-bearded ..	Punjab	1	15 and 40
52	Ranee	Punjab	1	40
53	Sardar	Punjab	1	40

TABLE XXVII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
54	Major	Punjab	1	40
55	Chandausi	Bombay-Deccan and Baroda State	3	15 and 42
56	C. P. Wheat ...	United Provinces	1	15 and 40
57	Kathia	United Provinces and Central Provinces	2	15 and 42
58	Malvi	Central India	1	42
59	Haura	Central Provinces	1	42
60	Jalalia	Central Provinces	1	42
61	Ochra Durum ...	Central India	1	15
62	Ekdma Durum ...	Central India	1	40
63	Narsingh Durum ...	Central India	1	40
64	Jaipur Wheat ...	Bihar	1	15
65	Khapli	Central Provinces and Bombay-Deccan	5	15 and 42
66	Bansi	Central Provinces, Hyderabad-Deccan and Bombay-Deccan	12	15, 24, 40 and 42
67	Pivla-Bansi... ...	Bombay-Deccan	1	42
68	Bodke	Bombay-Deccan	1	15 and 42
69	Daudkhani ...	Bombay-Deccan	8	15 and 42
70	Joneira	Bombay-Deccan	2	15 and 42
71	Gorya	Bombay-Deccan	2	15 and 42
72	Wagia	Bombay-Deccan and Baroda State	4	15 and 42
73	Potia	Bombay-Deccan	1	15
74	Charoli	Bombay-Deccan	1	15 and 42
75	Saraba	Bombay-Deccan	1	15
76	Popana	Bombay-Deccan	1	15
77	Pissi	Bombay-Deccan and Central India	2	15 and 42
78	Sudhe	Bombay-Deccan	2	15 and 24

TABLE XXVII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
79	Phadani	Bombay-Deccan	2	15, 24 and 42
80	Gahu	Bombay-Deccan	1	15 and 42
81	Patharia	Bombay-Deccan	1	42 and 75
82	Baxi	Bombay-Deccan	2	15, 40 and 42
83	Butka-Baxi Awnless ...	Bombay-Deccan	1	15
84	Popatya	Bombay-Deccan	1	15
85	Dohad wheat ...	Bombay-Deccan	1	42
86	Mundi	Bombay-Deccan	2	40, 42 and 75
87	Kathapulla ...	Bombay-Deccan	1	42
88	Katha Red ...	Junagad State and Baroda State	5	15 and 42
89	Katha Wagia ...	Junagad State	1	42
90	Arisigodhumai ...	Madras	1	15
91	Akkigodhumai ...	Madras	1	15
92	Calif	Sind	1	15
93	Yetna	Sind	1	15
94	Macoroni	Punjab	1	42
95	Bluechaff	Punjab	1	40 and 42
96	Durum	Punjab	1	15
97	Marquis	Punjab	1	15
98	Vernal	Punjab	1	15, 40 and 75
99	Kota	Punjab	1	15 and 40
100	Reward Ottawa ...	Punjab	1	42
101	Garnet Ottawa ...	Punjab	1	75
102	Kononso	Punjab	1	15 and 40
103	Federation ...	Punjab	1	15
104	Sunset	Punjab	1	42
105	Bolis	Punjab	1	42

TABLE XXVII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
106	Jypsum	Punjab	1	40 and 42
107	Utac U. S. A. ...	Punjab	1	40
108	Ceres U. S. A. ...	Hyderabad-Deccan ...	1	40 and 42
109	Hope	Hyderabad-Deccan and United Provinces	3	15, 40 and 42
110	Wisconsin	Hyderabad-Deccan ...	1	42
111	Hard Red	Hyderabad Deccan ...	1	15
112	Hard White ...	Bombay-Deccan	1	42
113	Australian	Bombay-Deccan	2	15, 24 and 42
114	Setparner	Bombay-Deccan	2	15, 40 and 42
115—182	Local wheat ...	The Punjab (35 different stations)	68	15, 24, 40, 42 and 75
183—193	Local wheat ...	Kashmir (10 different stations)	11	15, 40 and 42
194—197	Local wheat ...	N.-W. F. Province (3 different stations)	4	15 and 42
198—199	Local wheat ...	Baluchistan (1 station) ...	2	15
200—203	Local wheat ...	Delhi (1 station)	4	15, 24, 40, 42 and 75
204—260	Local wheat ...	United Provinces (35 different stations)	57	15, 40, 42 and 75
261—273	Local wheat ...	Nepal (10 different stations) ...	13	15, 40, 42 and 75
274—278	Local wheat ...	Bihar (5 different stations) ...	5	15, 42 and 75
279	Local wheat ...	Assam (1 station)	1	42
280—285	Local wheat ...	Rajputana (4 different stations)	6	24, 40 and 42
286—290	Local wheat ...	Central India (4 different stations)	5	15, 40 and 42
291—296	Local wheat ...	Central Provinces (5 different stations)	6	15, 40 and 42
297—299	Local wheat ...	Baroda State (2 different stations)	3	40 and 42
300	Local wheat ...	Kathiawar (1 station) ...	1	42
301—333	Local wheat ...	Bombay-Deccan (25 different stations)	33	15, 40, 42 and 75
334—336	Local wheat ...	Hyderabad-Deccan (1 station)	3	15 and 42
337—348	Local wheat ...	Mysore State (5 different stations)	12	15, 40 and 42
349—367	Local wheat ...	Madras Presidency (14 different stations)	19	15, 40 and 42

TABLE XXVIII

Varieties of barley from which samples of Puccinia graminis tritici *were collected for study during 1931-37 and the Physiologic Races found on each*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
1	Punjab Type 13 ...	Punjab	2	15, 40 and 42
2	Type 17	Bihar	1	15 and 40
3	Type 21	Bihar	1	15
4	II-187	Bihar	1	15
5	Two rowed Special ...	Punjab	1	42
6	Jaipur barley ...	Central India	1	42
7	Alwar barley ...	Central India	1	40 and 42
8	Satu	Bombay-Deccan	1	40
9—16	Local barley ...	Punjab (5 different stations) ...	8	15 and 42
17—19	Local barley ...	Kashmir (3 different stations)...	3	15
20—21	Local barley ...	Delhi (1 station)	2	15 and 42
22—27	Local barley ...	United Provinces (6 different stations)	6	15, 40, 42 and 75
28	Local barley ...	Bihar (1 station)	1	15
29	Local barley ...	Rajputana (1 station) ...	1	42
30	Local barley ...	Bombay-Deccan (1 station) ...	1	42
31—32	Local barley ...	Madras (2 different stations) ...	2	42

Breeding of varieties of wheat resistant to only six physiologic races of black rust, that have been found in India so far, is obviously more promising than is the case in countries with a temperate climate, where on account of the presence of barberries practically all over the area under wheat cultivation, the number of physiologic races is very large.

Further, the recurrence of epidemics of this rust should be effectively controlled in this country by the cultivation of resistant varieties in the hills only, i.e. over less than 5 per cent area, because rusts are re-introduced into the plains every year from the hills.

Unfortunately, over the greater part of the country wheat suffers from two other rusts, i.e. brown and yellow, caused by *P. triticina* and *P. glumarum* respectively. The source of both these rusts, like the black, lies in the hills. Consequently, for

the country as a whole, the real need is a wheat that would resist all the three rusts, i.e. the various physiologic races of each.

The occurrence of race 15, which is very virulent affecting, as it does, all the differential hosts except Khapli (*Triticum dicoccum*) and that of race 42, to which Khapli itself is susceptible, makes the task of the plant breeder more difficult than the small number of races would suggest.

Reference may here be made to the possibility of the appearance of new races by mutation as has been recorded by Stakman, Levine and Cotter [1930] in the case of race 1 of *P. graminis tritici* from which a mutant appeared after 13 years. As stated before, the writer has not found any case of mutation in the single spore cultures of this rust in the uredostage, one of which is as many as 100 generations old. Waterhouse [1929, 2] and Newton and Johnson [1932] came across cases of mutation in the colour of uredosori but not in pathogenicity. Stakman, Hines, Cotter and Levine [1932] have observed that mutation in pathogenicity is rare and that apparently barberry is primarily responsible for the origin of new forms (races).

16. Tests for seedling resistance

During the course of these studies, a large number of indigenous and foreign wheats were tested for seedling resistance, separately to each of the single spore cultures of the physiologic races of this rust.

The differential hosts of *P. triticina* and *P. glumarum* were also included in the list of varieties that were tested, so that the plant breeder might have a wider choice of resistant varieties for his work.

Since 1935, investigations have been in progress in co-operation with the Imperial Economic* Botanist for the breeding of resistant varieties for cultivation in the hills. Results of tests with differential hosts of *P. triticina* and *P. glumarum* are given in Table XXIX. A detailed account of reactions of other varieties, indigenous, foreign as well as the crosses raised from them, will be published in due course.

Table XXIX

Reactions of the differential hosts of P. triticina *and* P. glumarum *to Physiologic Races of* P. graminis tritici *met with in India so far.*

Serial No.	Name of variety	Races of *P. graminis tritici*					
		15	21	24	40	42	75
		Types of reactions					
	Differential hosts of P. triticina						
1	Malakof	4	0;	4	4	4	3
2	Carina	4	3-4	1-2	4	2=	4

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TABLE XXIX—*contd.*

Serial No.	Name of variety	Races of *P. graminis tritici*					
		15	21	24	40	42	75
		Types of reactions					
	Differential hosts of P. triticina						
3	Brevit	4	3-4	3-4c	4	2=	4
4	Webster	3	3-4	1, 0;	4	2-3	4
5	Loros	3-4	4	1-2	4	2	4
6	Mediterranean	3	4	4	4	4	4
7	Hussar	4	4	4	4	4	4
8	Democrat	4	4	4	4	4	4
	Differential hosts of P. glumarum						
9	Michigan Amber	4	4	4	4	2, 3	4
10	Blé rouge d'Ecosse	4	3-4	4	4	4	4
11	Strubes Dickkopf	4	3-4	4	4	3-4	4
12	Webster C. I. 3780	3-4	3-4	1, 0;	4	2-3	4
13	Holzapfels früh	4	4	4	4	4	4
14	Vilmorin 23	4	4	4	3-4	3-4	4
15	Heines Kolben	4	4	0-1, 0;	4	2=	2
16	Carstens V	4	4	4	4	3-4	4
17	Spaldings prolific	4	4	4	4	4	4
18	Rouge prolifique barbu	4	4	4	4	4	4
19	Chinese 166	4	4	4	3-4	3-4	4

17. TESTS FOR ADULT RESISTANCE

A considerable number of wheats, indigenous as well as foreign, has been tested for adult resistance with a mixture of all the six races of *P. graminis tritici.* These tests have yet to be conducted on some more varieties and the results will, therefore, be published on completion of the work.

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PART THREE

Physiologic Races of *Puccinia graminis avenae* (Pers.) Eriks. & Henn. (Black Stem-rust of oats)

19. Review of literature

Stakman, Levine and Bailey [1928], after preliminary tests with many varieties of oats, separated four forms (races) out of 100 collections. Later on Bailey [1925] isolated five biologic forms (races) one of which was new.

Gordon and Bailey [1928] reported six races from Canada, including one not met with before.

In Australia, Waterhouse [1929] found five races, one of which had not been described by previous workers.

Gordon [1929] came across race 7 in Canada, which was first reported by Waterhouse from Australia. Gordon and Welsh [1932] tested a large number of collections from different parts of Canada and isolated nine races, out of which two were new.

In U. S. A., Levine and Smith [1937] met with race 10 along with four others.

Lastly Lehmann, Kummer and Dannenmann [1937] have given a summarized account of work on this rust showing the range of infection, on the differential hosts, of ten different races.

20. Rust collections and their analysis

During the present studies, the differential hosts, analytical key and the symbols used were the same as employed originally by Stakman, Levine and Bailey [1928].

As stated in Part One, this rust was first found during these studies at higher altitudes in the Nilgiris. It is not known to occur in any other part of the country so far. The number of collections, therefore, has been very small. Four races have been isolated from the collections made during 1933-37. The races are 3, 4, 6 and 7, out of which race 3 has not been found alone in any collection so far.

Detailed information regarding the composition of the different collections, types of infection produced by each of the four races, as studied from single spore cultures and the tests leading to the identification of races occurring alone or in mixtures is supplied in Tables XXX-XXXIX.

TABLE XXX

Physiologic races of Puccinia graminis avenae *met with in ten samples of black rust of oats from the Nilgiris*

(Collections from altitudes of nearly 6,500-7,400 ft. above sea level, obtained during the years 1933-37)*

Serial No.	Places of rust collections	1933-34		1934-35		1935-36		1936-37	
		No.	Races	No.	Races	No.	Races	No.	Races
	Nilgiris								
1	Ketti	1	4, 6, 7	...	...	1	6, 7	...	...
2	Adashola	...	...	1	3, 6	...	...	...	...
3	Hoobathalai	1	4, 6, 7	...	...	...	...	...	...
4	Anikorai	1	3, 4	1	4	...	...	...	...
5	Fingerpost	1	6, 7	...	...	...	...	...	...
6	Kilkavati	...	...	...	...	1	4	1	7
7	Ootacamund	...	...	...	...	1	4	...	...
		4	3, 4, 6, 7	2	3, 4, 6	3	4, 6, 7	1	7

Total number of collections 10
Races met with ... ... 3, 4, 6 and 7

*Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

TABLE XXXI

History of single spore cultures of P. graminis avenae

Race	Name of station and original host	Stock collection or isolation	Started in	Age in generations	No. of tests made
3	Anikorai-Local ...	Stock ...	Sept., 1934 ...	50	8
4	Anikorai-Local ...	Rich (3) ...	May, 1936 ...	28	5
6	Ketti-Local ...	Stock ...	Sept., 1934 ...	50	8
7	Hoobathalai-Local	Stock ...	May, 1934 ...	56	5

TABLE XXXII

Types of infection produced by single spore cultures of the different physiologic races of Puccinia graminis avenae *met with in India so far*

Race	White Tartar	Joanette	Richland
3	4	0;	2
4	4	0—1	4
6	4	4	4
7	4	4	2

TABLE XXXIII

Means of infection of the physiologic races of Puccinia graminis avenae *that have been found in India, as recorded in the key prepared by Stakman, Levine and Bailey*

Race	White Tartar	Joanette	Richland
3	4—	1—	2
4	4	1	4+
6	4+	4+	4+
7	4	3+	2—

TABLE XXXIV

Series of inoculations leading to the identification of Race 4 of Puccinia graminis avenae

Place and year of collection *:—Fingerpost (Nilgiri Hills, Madras) ; 1935-36*
Host *:—Oats " Local "*

Stock or isolation	White Tartar	Joanette	Richland	Race
Stock	$\frac{5}{5}$ (3)	$\frac{0}{6}$ (0;)	$\frac{8}{8}$ (3—4)	4
Rich (3—4) ...	$\frac{6}{6}$ (3—4)	$\frac{0}{7}$ (0;)	$\frac{5}{5}$ (3—4)	4

Table XXXV

Series of inoculations leading to the identification of Race 6 of Puccinia graminis avenae

Place and year of collection :—Thambutti (Nilgiri Hills, Madras) ; 1936

Host :—Oats " Local "

Stock or isolation	White Tartar	Joanette	Richland	Race
Stock	$\frac{5}{5}$ (4)	$\frac{3}{4}$ (4)	$\frac{8}{8}$ (8—4)	6
Rich (8—4) ...	$\frac{4}{5}$ (8—4)	$\frac{5}{5}$ (8—4)	$\frac{5}{5}$ (8—4)	6

Table XXXVI

Series of inoculations leading to the identification of Race 7 of Puccinia graminis avenae

Place and year of collection :—Kilkavatti (Nilgiri Hills, Madras) ; 1936-37

Host :—Oats " Local "

Stock or isolation	White Tartar	Joanette	Richland	Race
Stock	$\frac{7}{7}$ (4)	$\frac{6}{7}$ (4)	$\frac{10}{10}$ (2)	7
White Tartar (4) ...	$\frac{6}{8}$ (4)	$\frac{4}{5}$ (4)	$\frac{5}{7}$ (2)	7

TABLE XXXVII

Series of inoculations leading to the identification of Races 3 and 4 of Puccinia graminis avenae

Place and year of collection :—Anikorai (Nilgiri Hills, Madras) ; 1933-34
Host :—Oats "Local"

Stock or isolation	White Tartar	Joanette	Richland	Race
Stock	8/9 (4)	0/2 (0;)	10/10 (2++,3?)	
* S.S.	11/11 (3—4)	0/4 (0;)	3/3 (2)	3
Rich (3?) ...	18/18 (4, 3cn)	0/7 (0;)	9/9 (4)	4

* S.S. denotes single spore culture.

TABLE XXXVIII

Series of inoculations leading to the identification of Races 3 and 6 of Puccinia graminis avenae

Place and year of collection :—Adashola (Nilgiri Hills, Madras) ; 1934-35
Host :—Oats "Local"

Stock or isolation	White Tartar	Joanette	Richland	Race
Stock	10/10 (4)	4/9 (3cn)	6/6 (3+cn, 2?)	
Rich (2?) ...	6/6 (4)	0/6 (0;)	6/6 (2)	3
Joan (3cn) ...	6/6 (4)	12/12 (3cn)	5/5 (4)	6

TABLE XXXIX

Series of inoculations leading to the identification of Races 6 and 7 of Puccinia graminis avenae

Place and year of collection :—Ketti (Nilgiri Hills, Madras) ; 1935-36

Host :—Oats "Local"

Stock or isolation	White Tartar	Joanette	Richland	Race
Stock	6/6 (4)	10/10 (4)	6/6 (2, 3)	
Rich (8) ..	5/8 (4)	3/5 (4)	3/5 (3+)	6
Rich (2)	6/6 (4)	5/6 (4)	6/6 (2)	7

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PART FOUR

Physiologic Races of *Puccinia triticina* Eriks. (Brown rust of wheat)

22. Review of literature

Occurrence of physiologic forms (races) within this species was first proved by Mains and Jackson [1926], who isolated twelve races with different reactions on eleven differentials in U. S. A.

Appel [1928] after a study of collections from twelve different localities in Finland, Germany and Upper Bavaria found four races, three of which were new. Scheibe [1928] described three more new races from Germany, Finland, etc.

In Australia, Waterhouse [1929] was able to identify two races after the addition of 'Thew' to the list of differential hosts, used by Mains and Jackson.

Wellensiek [1930] reported the occurrence of three races in the Netherlands.

In Bulgaria, Dodoff [1931] was able to isolate seven races from sixty-three cultures of this rust and observed that races 13 and 20 were more common than the rest.

Johnston and Mains [1932] issued a key along with tables showing the types of infection produced by fifty-three different races found till then in different parts of the world and reduced the original number of eleven differentials to eight.

Radulescu [1932] isolated ten races from forty-nine collections, mostly from Rumania and a few from Germany, Sweden, Finland and Greece.

From India, Mehta [1933] reported the occurrence of race 10 and a new race not described by Johnston and Mains.

In addition to races 11, 13, 14 and 15, previously reported from Germany by Scheibe, Stroede [1934] found four races, all of which had been recorded to occur elsewhere by Johnston and Mains.

In Italy, Sibilia [1934] found race 15 as described by Scheibe.

Schilcher [1935] isolated six races from collections of this rust made in Austria and Hungary.

In a later contribution, Sibilia [1935] described eight new races from Italy, not included in Johnston and Mains' key.

Waterhouse [1936] numbered the Australian races described by him in 1929 as Australian 1 and 2, by further differentiation of race 26 with the help of variety 'Thew.'

From England and Wales, Miss Roberts [1936] reported eight new races. She also obtained collections from Portugal and isolated two new races from them.

Goeschele [1936] recorded the occurrence of five races in the Odessa region of U. S. S. R., all of which had been found elsewhere.

Eleven other races were reported to occur in U. S. S. R., as isolated by Rashevskaya and Barmenkoff [1936] from collections from twenty different places. Out of these eleven races, six were new.

In another contribution from Italy, Sibilia [1936] reported the occurrence of eight more new races of this rust, as well as race 25, thereby bringing the total number of races in Italy to eighteen.

In the year 1936, Humphrey, Johnston and Caldwell issued a revised key of eighty-six races of *P. triticina*. In this key the new race (formerly called 58) reported from India [Mehta, 1933] was re-numbered as 63. In a supplement to the key for the study of this rust, these authors added four more races bringing the total number to ninety. Their latest key deals with one hundred and eight races.

In a recent contribution from Russia, Petrusheva [1937] reported the occurrence of four races in the Leningrad region, one out of which was new to that country. While summing up the results of investigations on the physiologic races of this rust in U. S. S. R. from 1931-36, Barmenkoff [1937] stated that twenty-five different races had been found in that country.

In Poland, Ralski [1937] found five races, none of which was new.

Hassebrauk [1937], reported the occurrence of eight races after a study of sixty collections, mostly German but a few from Belgium, Finland, Czechoslovakia, Hungary, Bulgaria, Italy, Greece and Turkey during 1934. In 1935, in addition to the above, six races, including three new, were found in collections from those countries.

23. Differential hosts

In these studies, only eight differential hosts finally selected by Johnston and Mains [1932] were used. The list is as follows :—

Malakof, Carina, Brevit, Webster, Loros, Mediterranean, Hussar and Democrat. They are all varieties of common wheat. The symbols (0, 1, 2, 3 and 4) are the same as used by Johnston and Mains in their key. The explanation of symbols is more or less the same as described in Part One, on the authority of Stakman and Levine's work.

24. Rust collections and their analysis

The methods of study have been described in Part One and need not, therefore, be repeated here.

Details regarding the composition of fifteen collections of 1930-32 have been supplied in an earlier article [Mehta, 1933]. As stated therein, only two races

were isolated, i.e. race 10 and a new race which had not till then been obtained from any other country. Since then, 393 collections of this rust in the uredostage, including 111 from hills and hilly tracts, have been analysed. In all, six physiologic races, including the two referred to above, have been found. These are 20, A, B and C. The new race reported in 1933 was first called 58 but recently the International No. 63 has been allotted to it. Detailed reactions of races A, B and C, all of which are new, have been sent to Dr. H. B. Humphrey, Principal Pathologist, Department of Agriculture, U. S. A., for assignment of International numbers.*

As stated before, collections from hills have a special importance in this country because of oversummering of rusts in the uredostage in those parts and also on account of the occurrence of *Thalictrum*, only in the hills. Keeping these facts in view, a much larger number of collections was obtained from the hills than was necessary from an acreage covering less than 5 per cent of the total area under wheat.

Names of places wherefrom collections were obtained during the last five years as well as the composition of samples from each locality are shown in Tables XL-XLVII.

No collection of the aecidial stage of this rust on species of *Thalictrum* was available. *T. flavum*, the most susceptible species of the genus does not occur in India. Inoculations made on wheat during the present studies, with aecidiospores occurring in nature on *T. javanicum* and *T. foliolosum*, in a forest near Simla during August-September, gave negative results in every case.

Barclay [1887] found aecidia on *T. minus* 126 miles from Simla on the Hindustan-Tibet Road as well as on *T. javanicum* and Arthur and Cummins [1933] have recorded the occurrence of *Puccinia Rubigo-vera* (DC.) Wint. on species of *Aquilegia* and *Thalictrum* from specimens collected by Stewart in some of the hills in India, but there is no experimental proof of their connection with the brown rust of wheat.

As stated in Part Two under black rust, there is no case on record, with necessary data, of an outbreak of this rust either on wheat, which could be connected with infected plants of *Thalictrum* in this country.

According to Butler and Bisby [1931] the aecidia occurring on *T. javanicum* and possibly also on *T. minus* found by Barclay [1887] belong to *Aecidium urceolatum*.

The rôle of indigenous species of *Thalictrum* will be fully discussed in Section II.

* Intimation has just been received that races A, B and C have been assigned International numbers 106, 107 and 108 respectively.

Table XL

Physiologic Races of Puccinia triticina *met with in thirty-eight samples of brown rust of wheat from the Punjab and Kashmir*

(Collections from altitudes of nearly 3,000-9,000 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab										
1. Narkunda ...	1	63	1	63	1	63	1	20, 63	...	...
2. Mattiana	1	63	...	..	..	...	1	B, 63	...	...
3. Theog	...	...	1	63	1	10, 63	1	63	..	...
4. Fagu	...	...	..	..	1	63	...	...	1	20
5. Kufri	...	...	..	...	...	...	1	63	...	...
6. Simla	1	63	1	10, 63	1	20, 63	1	63	...	...
7. Kandaghat ...	...	...	...	...	1	20, 63	...	...	...	...
8. Solon	...	...	...	...	1	63	1	20, 63	...	...
9. Kasauli	...	...	1	63	...	...	1	63	...	...
10. Dharampore ...	1	10	...	...	...	...	1	63	...	...
11. Manali	...	...	...	...	...	...	1	63	...	...
12. Palampore ...	...	...	...	...	..	...	.	...	1	20, 63
13. Kangra	2	10, 63	...	...	...	...	...	...	...	...
14. Murree	...	...	...	...	...	...	1	20, 63	...	...
15. Ghoragali... ...	1	10, 20	...	...	...	...	...	...	...	...
16. Dalhousie ...	...	..	...	...	...	...	1	63	...	...
Kashmir										
17. Pahalgam ...	...	...	...	...	...	...	1	63	..	...
18. Martand (Achhabal) ...	...	...	...	...	...	...	1	B, 63	...	...
19. Batote	...	...	...	...	...	...	1	20, 63	...	...
20. Ikhrajpura ...	...	...	..	...	...	...	1	63	...	...
21. Pattan	...	...	...	...	...	..	1	63	...	...
22. Ganeshpura ...	...	...	...	...	...	...	1	63	...	...
23. Fisalna	...	...	...	...	...	...	1	20, 63	...	...
24. Vernag	...	...	...	..	...	...	1	63	...	...
	7	10, 20, 63	4	10, 63	6	10, 20, 63	19	B, 20, 63	2	20, 63

Total number of collections 38
Races met with ... ... B, 10, 20 and 63

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

TABLE XLI

Physiologic Races of Puccinia triticina *met with in sixty-five samples of brown rust of wheat from the Punjab, Kashmir, N.-W. F. Province, Sind and Delhi*

(Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab										
1. Koti	...	...	...	...	1	63	1	63	...	...
2. Koti-Kalka ...	...	...	...	...	...	...	...	...	1	63
3. Kalka	1	63	..	...	...	...	...	...	..	..
4. Ambala	1	63	...	...	...	...	...	...	1	20, 63
5. Karnal	5	10, 63	2	10, 63	1	20	5	10, 20, 63	1	20
6. Rupar	...	...	...	...	1	63	...	...	...	...
7. Lahore	1	63	...	...	1	B	...	...	..	..
8. Lyallpur	4	10, 63	1	63	2	A, B, C	5	20, 63	2	10, 20
9. Hoshiarpur ...	2	10, 63	...	...	...	...	...	...	...	...
10. Una	1	10, 63	...	...	...	...	...	...	...	...
11. Gurdaspur ...	1	10	...	...	1	B, 20	...	...	1	20
12. Pathankote ...	1	63	...	...	1	20, 63	...	...	...	...
13. Khanewal ...	...	...	1	20, 63	1	B	...	...	...	...
14. Jullundur ...	1	10, 63	...	...	1	63	...	...	...	...
15. Amritsar	...	...	1	20, 63	...	...	...	...	...	...
16. Lower-Kangra Valley	1	10, 63	...	...	...	...	...	...	...	...
17. Barakao	1	10	...	...	...	...	...	...	...	...
18. Wazirabad ...	1	10, 63	...	...	...	...	...	...	...	...
19. Sialkot	...	...	...	...	...	...	...	...	1	10, 63
20. Rawalpindi ...	1	10	1	20	1	B	...	...	...	...
Kashmir										
21. Jammu	1	10, 63	...	...	...	...	...	...	...	...
N.-W. F. Province										
22. Bannu	...	...	1	20	...	...	...	...	...	...
Sind										
23. Sakrand	...	...	1	10	...	...	...	...	...	...
Delhi										
24. Delhi	1	10, 63	1	63	1	20	1	20, 63	1	63
	24	10, 63	9	10, 20, 63	12	A, B, C, 20, 63	12	10, 20, 63	8	10, 20, 63

Total number of collections 65

Races met with ... ... A, B, C, 10, 20 and 63

TABLE XLII

Physiologic Races of* Puccinia triticina *met with in thirty-five samples of brown rust of wheat from the United Provinces and Nepal

(Collections from altitudes of nearly 3,000-7,500 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Kumaon Hills										
1. Almora	1	10, 63	...	...	...	...	...	...	...	...
2. Sameshwar ...	1	63	...	...	...	...	...	...	...	...
3. Bageshwar ...	1	10, 63	...	...	...	...	...	...	...	...
4. Tarikhet	...	...	1	63	...	...	...	...	...	...
5. Bhimtal	...	...	1	20, 63	...	...	...	...	...	...
6. Champawat ...	...	...	1	63	...	...	...	...	...	...
7. Jeolikote	1	63	...	...	1	63	...	...	...	...
8. Eastern Kumaon ...	...	...	1	63	1	63	...	...	...	...
Sewalik Range										
9. Chakrata ...	1	10, 63	...	...	...	...	...	...	...	...
10. Saiah	...	...	1	63	...	...	...	...	1	20, 63
11. Lansdowne ...	...	...	1	10, 63	...	...	...	...	...	...
Nepal										
12. Asurkot	...	...	...	...	...	...	1	63	...	...
13. Khilchi	...	...	...	...	...	...	...	...	1	20, 63
14. Tansingh ...	1	10, 63	...	...	...	...	1	63	...	...
15. Piuthan	...	...	...	...	3	20, 63	1	63	1	63
16. Balkot	...	...	...	...	1	B, 63	1	20, 63	...	...
17. Riri	...	...	...	...	...	...	1	63	1	63
18. Wangla	...	...	...	...	1	20	...	...	1	10, 63
19. Galkot	...	...	...	...	...	...	...	...	1	63
20. Sanachidki ...	...	...	...	...	...	...	...	.	1	20, 63
21. Pipari	1	10	...	...	...	...	...	...	...	...
22. Sallyana	...	...	...	...	1	63	...	...	...	...
23. Sishni	...	...	...	...	...	...	1	63	...	...
24. Bervas	...	...	...	...	...	...	1	20	...	...
	7	10, 63	6	10, 20, 63	8	B, 20, 63	7	20, 63	7	10, 20, 63

Total number of collections 35
Races met with ... ... B, 10, 20 and 63

*Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

Table XLIII

Physiologic Races of Puccinia triticina *met with in 113 samples of brown rust of wheat from the United Provinces*

(Collections from the plains and altitude below 3,000 ft. obtained during the years 1932-37)

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Race
1. Dogadda	...	...	1	63	...	...	...	...	1	63
2. Kathgodam ...	1	10, 63	...	...	...	...	...	...	...	...
3. Haldwani... ...	...	...	1	A, 63	1	20, 63	1	63	...	...
4. Nepalganj ...	1	10, 63	1	63	1	20	1	20, 63	1	20
5. Kotdwara ...	...	...	1	10, 63	...	...	...	...	1	63
6. Mailani	...	...	...	...	1	63	1	63	1	20, 63
7. Pilibhit	...	...	...	...	1	63	1	B, 20, 63	1	63
8. Pachperwa ...	...	...	...	...	...	...	...	...	1	63
9. Bareilly	1	10	1	20, 63	1	63	1	20, 63	1	20, 63
10. Chandausi ...	1	10, 63	...	...	...	...	...	...	...	...
11. Nautanwa ...	1	10, 63	1	20, 63	1	20, 63	1	20, 63	1	63
12. Gainsari	...	...	...	...	...	...	1	63	1	63
13. Dehra Dun ...	...	...	1	10, 63	1	20, 63	1	63	...	...
14. Gorakhpur ...	1	10, 63	1	63	1	20	3	20, 63	3	63
15. Bellrein	...	...	...	...	1	63	1	63	...	...

TABLE XLIII—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No	Races	No	Races
16. Gonda	1	10, 63	...	...	1	63	1	63	..	..
17. Bahraich	...	...	...	...	2	63	1	63	2	10, 20, 63
18. Simra	1	63	...	...	...	...	...	...	...	...
19. Choharpur ...	...	...	1	20, 63	...	...	...	...	1	20, 63
20. Sitapur	...	...	...	..	1	63	1	63	1	63
21. Barabanki ...	2	10, 63	...	...	1	20, 63	1	20, 63	...	...
22. Lucknow ...	1	10, 63	1	20, 63	...	...	...	...	1	63
23. Fyzabad	2	20, 63	1	10	...	...	8	20, 63	...	...
24. Shahjahanpur ...	...	...	1	10, 63	1	20, 63	...	...	...	...
25. Najibabad ...	...	...	...	...	...	...	1	20, 63	...	...
26. Khalilabad ...	...	...	...	...	...	...	1	63	...	...
27. Chalti	...	...	...	...	1	63	...	...	...	...
28. Cawnpore ...	8	10, 63	1	63	2	20, 63	...	...	1	20, 63
29. Allahabad ...	1	10	1	20, 63	1	20	...	...	3	63
30. Benares	2	10	...	...	1	C, 20	...	..	1	63
31. Agra	4	10, 63	1	63	2	20, 63	5	B, 20, 63	1	63
32. Jhansi	...	...	1	63	2	20, 63	...	...	1	63
	28	10, 20, 63	16	A, 10, 20, 63	24	C, 20, 63	26	B, 20, 63	24	10, 20, 63

Total number of collections 118

Races met with ... ... A, B, C, 10, 20 and 63

TABLE XLIV

Physiologic Races of Puccinia triticina *met with in sixty-one samples of brown rust of wheat from Bihar, Bengal and Assam. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bihar										
1. Raxaul	...	...	1	63	...	...	1	63	1	63
2. Jogbani	1	63	...	...	...	...	1	63	1	63
3. Pusa	2	10, 63	1	63	2	10, 63	1	63	4	20, 63
4. Patna	...	...	1	63	2	20, 63	2	63	1	20, 63
5. Sabour	2	10, 63	1	20, 63	2	63	3	20, 63	1	63
6. Musheri	...	...	...	...	...	..	...	...	1	63
7. Harinagar ...	...	...	...	...	...	...	...	...	1	10, 63
8. Jaynagar ...	...	...	1	20	...	...	1	63	1	20, 63
9. Sitamarhi ...	..	...	...	...	...	...	1	63	1	63
10. Bhapatiahi ..	..	...	...	...	...	...	...	...	1	20, 63
11. Motihari	...	...	...	...	...	...	1	63	...	...
12. Katihar	...	...	1	63	..	...	1	63	...	...
13. Bagaha	...	..	...	...	...	...	1	63	..	...
14. Chapra	...	...	...	...	..	...	1	B	...	...
Bengal										
15. Nimtita	1	10, 63	1	20	2	20, 63	...	...	...	...
16. Malda	1	10, 63	1	63	1	20	2	63	1	63
17. Parbatipur ...	...	...	...	..	..	..	...	...	1	63
18. Singhjani ...	...	...	...	...	...	...	...	...	1	63
19. Mymensingh ...	...	...	...	..	...	...	...	...	1	10
20. Cooch-Bihar ...	...	...	...	...	..	...	..	...	1	63
21. Jalpaiguri ...	...	...	...	...	...	...	...	...	1	63
22. Rangpur	...	...	..	...	...	..	..	...	1	63
Assam										
23. Dhubri ...	...	...	...	...	...	...	...	...	1	63
	7	10, 63	8	20, 63	9	10, 20, 63	16	B, 20, 63	21	10, 20, 63

Total number of collections 61

Races met with ... ... B, 10, 20 and 63

TABLE XLV

Physiologic Races of Puccinia triticina *met with in twenty-two samples of brown rust of wheat from Rajputana, Central India and Central Provinces. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Rajputana										
1. Bharatpur ...	...	...	..	...	1	20	...	...	...	...
2. Jaipur	...	...	1	10	2	20	...	...	3	20, 63
3. Ajmer	...	...	1	63	1	20	...	...	...	...
4. Jodhpur	...	...	...	...	1	B	...	...	...	...
5. Sriganganagar ...	...	...	...	...	1	B	...	...	...	...
Central India										
6. Datia	...	...	1	20	1	10, 20	...	...	...	...
Central Provinces										
7. Saugor	...	...	...	...	1	63	...	...	...	...
8. Katni	...	...	...	...	1	63	...	...	...	...
9. Jubbulpore ...	...	...	1	20	3	20, 63	...	...	...	...
10 Kuksi	...	...	1	20	...	...	...	...	...	...
11. Khandwa... ...	...	...	1	10	1	20, 63	...	...	...	...
	...	...	6	10, 20, 63	13	B, 10, 20, 63	...	...	3	20, 63

Total number of collections 22

Races met with .. .. B, 10, 20 and 63

TABLE XLVI

Physiologic Races of Puccinia triticina *met with in thirty-eight samples of brown rust of wheat from Bombay-Deccan, Madras and Mysore. (Collections from altitudes* of nearly 3,000-7,000 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bombay-Deccan										
1. Mahabaleshwar ...	..	...	1	68	...	...	...	...	...	...
2. Chinchali ...	...	...	1	68	...	...	...	...	...	...
3. Deola	...	...	1	20	...	...	...	...	...	...
4. Deothan	...	...	1	20	...	...	...	...	...	...
Madras										
5. Thambatti ...	...	...	...	...	...	...	1	20	...	...
6. Kilkavati ...	...	..	...	...	...	...	1	B, 68	1	68
7. Ketti	...	...	...	...	...	...	2	B, 68	...	...
8. Ellenhatti ...	...	...	1	20, 68	...	...	1	68	...	...
9. Hoobathalai ...	...	...	1	63	...	...	...	...	...	...
10. Kallakorai ...	...	...	...	...	...	...	...	...	1	63
11. Doddani	...	...	...	...	2	B, 63	1	68	...	...
12. Anikorai	1	10	...	...	...	...	1	20, 68	...	..
13. Coonoor	1	10	...	..	...	...	...	...	...	...
14. Ootacamund ...	...	...	1	68	...	...	..	..	...	...
15. Adashola ...	...	...	...	...	...	...	...	...	1	10, 68
16. Nanjanad ...	...	..	...	..	1	68	..	..	..	...
17. Manjidala ...	...	...	...	...	1	20	1	68, A	...	...
18. Ithilar	...	...	...	...	1	68	...	...	...	...
19. Davani	...	...	..	...	1	B	...	...	...	...
20. Kodaikanal ...	1	10	...	...	...	...	1	20, 68	...	...

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

TABLE XLVI—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
21. Vilpatti	1	10	...	...	...	...	...	...	...	...
22. Lourudupuram ..	...	...	...	...	...	...	1	63	1	20
23. Mannavanur ...	...	...	...	...	...	..	1	20, 63	..	..
24. Kookal	...	...	...	...	..	...	1	63	...	...
25. Pottangi	...	...	2	20, 63	1	63	...	...	...	...
26. Kholla-Malai Hills ...	...	...	...	...	...	...	1	20	...	...
Mysore										
27. Hebbal (Bangalore) ...	1	63	...	...	...	...	...	...	...	...
	5	10, 63	9	20, 63	7	B, 20, 63	13	A, B, 20, 63	4	10,20, 63

Total number of collections 38
Races met with ... ... A, B, 10, 20 and 63

TABLE XLVII

Physiologic Races of Puccinia triticina *met with in twenty-one samples of brown rust of wheat from Baroda State, Bombay-Deccan, Hyderabad-Deccan, Mysore State and Madras. (Collections from the plains and altitudes below 3,000 ft., obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Baroda State										
1. Baroda	...	...	...	..	1	20	...	...	...	...
2. Jagudan	...	...	...	...	...	...	1	10	...	...
3. Amreli	...	...	...	...	1	63	...	...	...	...

TABLE XLVII—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bombay-Deccan										
4. Dohad	...	...	..	..	1	20, 63	...	...	...	...
5. Ahmedabad ...	...	...	...	...	1	10	...	...	...	...
Hyderabad-Deccan										
6. Himayatsagar ...	1	10	1	20, 63	...	...	...	...	...	...
Mysore State										
7. Mandya	1	63	...	...	...	...	...	...	...	...
Madras										
8. Coimbatore ...	2	10	1	63	1	63	...	...	1	63
9. Kallar	...	...	...	...	...	...	...	...	1	20
10. Tudiyalur ...	...	...	...	...	...	...	...	...	1	63
11. Ganapatti ...	...	...	...	...	...	...	...	...	1	63
12. Udumalpet ...	...	...	...	...	...	...	...	...	1	63
13. Palladam Khalli Paliyam	...	...	...	...	...	...	1	20, 63	...	...
14. Gojharia	...	...	...	...	...	...	1	20	...	...
15. Basuli	...	...	1	63	..	..	..	..	.	..
16. Sunki	...	...	...	...	1	63	..	...	...	...
	4	10, 63	3	20, 63	6	10, 20, 63	3	10, 20, 63	5	20, 63

Total number of collections 21
Races met with ... ... 10, 20 and 63

25. SINGLE SPORE CULTURES

A single spore culture of each of the six races, found in the country so far, has been maintained in the uredostage from the time it was first started. Out of these, two cultures are nearly seven years old and had completed their 100th generation by the end of July 1938. An account of the history of each culture is given in Table XLVIII. The range of infection of each of the races, that have been

tested on the differentials from time to time, is shown in Table XLIX. For the sake of comparison, the 'reaction of differential varieties' as recorded in Humphrey, Johnston and Caldwell's key issued in the year 1936 is given in Table L.

So far, no case of mutation has been observed in the pathogenicity of any of the six races under reference.

TABLE XLVIII

History of single spore cultures of Puccinia triticina

Race	Name of station and original host	Stock collection or isolation	Started in	Age in generations	No. of tests made
10	Lyallpur-Local ...	Stock ...	Dec., 1931 ...	100	11
20	Choharpur-Local ...	Hu (4) ...	May, 1935 ...	48	6
63	Simla-Local ...	Stock ...	Dec., 1931 ...	101	13
A	Haldwani-Local ...	Lor (3)-Br (4) ...	July, 1935 ...	46	6
B	Khanewal-Pb. 8A ...	Hu (3) ...	Sept., 1935 ...	48	5
C	Benares-Pusa 4 ...	Web (2) ...	Oct., 1935 ...	40	5

TABLE XLIX

Range of infection produced by single spore cultures of the different physiologic races of Puccinia triticina *met with in India so far*

Race	Malakof	Carina	Brevit	Webster C. I. 3780	Loros	Mediterranean	Hussar	Democrat
10	4	4	4	4	4	0-2	2-3	1-2
20	4	4	4	4	4	1-2	3-4	1-2
63	0 ;	1-2	2-3	0-1	1-2	1-2	0 ;	1-2
A*	0 ;	2-3	3-4	2-3	3	0 ;	0 ;	0 ;
B*	0 ;	4	4	4	4	1-2	3-4	1-2
C*	4	4	4	2-3	4	0-1	3-4	0-2

* These races, i.e. A, B and C, have been assigned Nos. 106, 107 and 108 respectively in the latest International Key by Humphrey, Johnston and Caldwell.

TABLE L

Reaction of differential varieties to Physiologic Races of P. triticina, *occurring in India, as recorded in Humphrey, Johnston and Caldwell's key,* issued in the year 1936*

Race	Malakof	Carina	Brevit	Webster C. I. 8780	Loros	Mediterranean	Hussar	Democrat
10	4	4	4	4	4	1-2	1-2	1-2
20	4	4	4	4	4	0		
63	0	1-2	2-3	0-1	1-2	1-2	0	1-2

* A cyclostyled copy of this key was kindly supplied by the authors to the writer, on request.

26. MIXTURES OF PHYSIOLOGIC RACES IN NATURE

Out of a total of 408 collections of *P. triticina* that have been studied so far, 117 were mixtures of two races or more. The remaining 291 collections yielded one race each. Details regarding the composition of 117 collections that proved to be mixtures are supplied in Table LI.

Series of inoculations leading to the identification of all the four races occurring alone are shown in Tables LII—LV. Races A and C have not been found alone.

Series of inoculations leading to the identification of each of the six races in representative combinations are shown in Tables LVI—LIX.

General information and summary of data concerning the analysis of 408 collections of *P. triticina* are given in Table LX.

TABLE LI

Composition of 117 collections of Puccinia triticina *that were found to be mixtures*

Number of combinations	Races	Total number of collections
1	10 and 20	2
2	10 and 63	44
3	20 and 63	58
4	20 and B	1
5	20 and C	1
6	63 and A	2
7	63 and B	6
8	A and C	1
9	10, 20 and 63	1
10	20, 63 and B	1

TABLE LII

Series of inoculations leading to the identification of Race 10 of Puccinia triticina

Place and year of collection :—Coonoor (Nilgiri Hills, Madras); 1932-33

Host :—Wheat " Akki "

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	5/5 (4)	6/6 (4)	5/6 (4)	4/6 (3-4)	5/5 (4)	2*/6 (0-1)	6/6 (2-3)	0/6 (0 ;)	10
Med (1) ...	2/2 (4)	5/5 (4)	7/7 (3-4)	6/6 (4)	6/6 (4)	6/8 (0-2)	7/7 (2-3)	6/6 (0-2)	10

* 3 leaves showed (0 ;) only

TABLE LIII

Series of inoculations leading to the identification of Race 20 of Puccinia triticina

Place and year of collection :—Cawnpore (United Provinces); 1934-35

Host :—Wheat " Pusa 12 "

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	5/5 (4)	5/5 (4)	6/6 (4)	6/6 (4)	5/5 (4)	5/5 (0-1)	6/6 (3-4)	5/5 (0-1)	20
Hu (4) ...	4/5 (4)	3/3 (4)	5/5 (4)	3/4 (4)	5/5 (4)	4/5 (0-2)	5/5 (3-4)	5/5 (0-1)	20

Table LIV

Series of inoculations leading to the identification of Race 63 of Puccinia triticina

Place and year of collection :—Theog (Simla Hills, Punjab) ; 1933-34

Host :—Wheat " Local "

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	0/4 (0 ;)	6/6 (1-2)	5/5 (2-3)	0/4 (0 ;)	5/5 (1-2)	1*/6 (0-1)	0/5 (0 ;)	6/6 (1-2)	63
Br (2-3) ...	0/6 (0 ;)	4/6 (1)	8/8 (2-3)	4/7 (0-1)	6/7 (1-2)	7/8 (1-2)	0/8 (0 ;)	7/8 (1-2)	63

* 5 leaves showed (0 ;) only

Table LV

Series of inoculations leading to the identification of new Race B of Puccinia triticina

Place and year of collection :—Jodhpur (Rajputana) ; 1934-35

Host :—Wheat " C. 499 "

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	0/4 (0 ;)	6/6 (4)	5/6 (4)	5/5 (4)	6/6 (4)	5/5 (0-2)	4/6 (3)	5/6 (0-2)	B
Web (4) ...	0/5 (0 ;)	6/6 (4)	6/6 (4)	4/4 (4)	7/7 (4)	4/4 (0-2)	5/5 (3)	6/6 (0-2)	B

TABLE LVI

Series of inoculations leading to the identification of Race 20 and new Race B of Puccinia triticina

Place and year of collection :—Gurdaspur (Punjab) ; 1934-35
Host :—Wheat "Pb. 8A"

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	6/6 (4)	5/5 (4)	5/5 (4)	3/5 (4)	5/5 (3-4)	2*/5 (1-2, 0 ;)	2/6 (3-4)	0/5 (0 ;)	
Web (4) ...	0/4 (0 ;)	5/5 (4)	4/4 (4)	5/5 (4)	5/5 (4)	5/5 (1-2)	5/5 (3-4)	5/5 (0-2)	B
Mal (4) ...	3/4 (4)	5/5 (4)	6/6 (4)	4/4 (4)	4/6 (4)	3/4 (1-2)	5/5 (4)	4/5 (1-2)	20

* Other leaves showed (0 ;)

TABLE LVII

Series of inoculations leading to the identification of Race 20 and new Race C of* Puccinia triticina

Place and year of collection :—Benares (United Provinces) ; 1934-35
Host :—Wheat "Pusa 4"

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	6/6 (4)	4/4 (4)	5/5 (4)	5†/5 (4, 2 ?)	7/7 (4)	3/5 (1-2, 0 ;)	6/6 (4)	3/5 (1-2)	
Hu (4) ...	4/5 (4)	4/5 (4)	5/5 (4)	5/5 (4)	2/4 (4)	4/4 (1-2)	4/4 (4)	4/4 (0-1)	20

* New Race C has not been found to occur alone. † 1 leaf showed (2 ?)

TABLE LVII—*contd.*

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Web. (2 ?) ...	4/4 (4)	3/4 (4)	4/5 (4)	4/4 (2)	6/6 (4)	4/4 (1-2)	6/6 (2-3)	3/5 (0-1)	C
[redacted] Web (2 ?) Hu (3)	6/6 (4)	5/5 (3)	3/3 (4)	5/5 (2)	5/5 (4)	4/4 (0-1)	4/4 (3)	0/6 (0 ;)	C
[redacted] Web (2 ?) Hu (2)	6/6 (4)	2/5 (3)	5/5 (4)	5/5 (2-3)	6/6 (3-4)	3/5 (0-1)	4/4 (3)	0/5 (0 ;)	C

TABLE LVIII

Series of inoculations leading to the identification of Race 63 and new Race A of Puccinia triticina

Place and year of collection :—Haldwani (United Provinces) ; 1933-34
Host :—Wheat "Local"

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	0/5 (0 ;)	8/8 (1-2)	6/6 (2-3)	3*/5 (0-1)	7†/7 (1-2, 3 ?)	1*/8 (0-1)	0/6 (0 ;)	1*/7 (0-1)	
Ca (1-2) ...	0/7 (0 ;)	3/8 (0-1)	6/8 (2-3)	2*/7 (0-1)	4/8 (0-2)	5/9 (0-2)	0/6 (0 ;)	7/8 (1-2)	63
Lor (3 ?) ...	0/7 (0 ;)	6/6 (1-2, 4)	6/6 (4)	7/7 (2, 4)	7/7 (3, 2 ?)	6/6 (1-2)	0/6 (0 ;)	6/6 (1-2)	
Lo (3 ?) Br (4). S. S.*	0/5 (0 ;)	5/5 (2-3)	5/5 (4)	4/4 (2-3)	4/4 (3-4)	0/4 (0 ;)	0/4 (0 ;)	0/4 (0 ;)	A

* Other leaves showed (0 ;)
† Only 2 pustules of 3 ? present on one leaf
New Race A has been met with in two collections only. Evidently this race was present in a very small quantity in the sample because it showed itself in the stock test on one leaf of Loros only in 2 pustules of (3 ?)
* S. S. denotes single spore culture.

Table LIX

Series of inoculations leading to the identification of Races 10, 20 and 63 of Puccinia triticina

Place and year of collection :—Karnal (Punjab) ; 1935-36
Host :—Wheat " Federation "

Stock or isolation	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	Race
Stock ...	3/4 (0 ;, 4)	5/5 (0 ;, 4)	4/5 (2-3)	5/5 (0 ;, 4)	2*/6 (0 ;, 3-4)	1*/6 (0-1)	5/5 (0-1, 4)	6/6 (1-2)	
Mal (4) ...	6/6 (4)	6/6 (4)	6/6 (4)	6/6 (4)	7/7 (4)	6/6 (1-2)	6/6 (4)	6/6 (1-2)	20
Br (2-3) ...	0/6 (0 ;)	3*/5 (0-1)	4/4 (2-3)	1*/5 (0-1)	6/6 (0-1)	1*/5 (0-1)	0/5 (0 ;)	0/5 (0 ;)	63
Hu (1) ...	7/7 (4)	5/5 (4)	5/5 (4)	5/5 (4)	5/5 (4)	5/5 (0-2)	6/6 (2-3)	5/5 (0-2)	10

* Other leaves showed (0 ;) only.

Table LX

General information and summary of data concerning 408 collections of P. triticina *that have been analysed so far*

I. Number of collections from hills and hilly tracts :—
  (i) The Punjab, United Provinces, Nepal and Kashmir ... 78
  (ii) Western Ghats, Nilgiri and Palni hills 88

II. Percentage of collections from hills and hilly tracts ... ... over 28 (116/408)
  It might be mentioned that the area under wheat in the hills is less than 5 per cent of the entire acreage under this crop.

III. Races met with ... ... 10, 20, 63, A, B and C.

IV. Races found in the hills and hilly tracts ... ... 10, 20, 63, A and B.

V. Races found in the plains ... ... 10, 20, 63, A, B and C.

VI. Composition of collections :—

			Alone	In combination
(i)	Number of collections showing Race	10 ...	39	47
(ii)	Ditto	20 ...	50	64
(iii)	Ditto	63 ...	192	112
(iv)	Ditto	A ...	...	8
(v)	Ditto	B ...	10	8
(vi)	Ditto	C ..	...	2

VII. Out of 408 collections 117 were mixtures as per details given below :—
  (i) Collections containing two races 115
  (ii) ,, ,, three races 2

27. Distribution and prevalence

During 1930-31 only two collections were made, consequently, the information supplied below refers to a period of six years only (1931-37). As in the case of black rust, the country has been divided into five areas (A, B, C, D and E) for the sake of convenience of reference. The boundaries of these areas are shown in Map No. 1.

As shown in Table LXI, races 10, 20, 63 and B are found in all the five areas. Race A has been found in the first two and the fifth, while race C only in the first two areas.

With regard to their prevalence, it may be stated that :—

(i) Race 63 is the most predominant, taking the country as a whole.

(ii) Race 20 comes next and it happens to be the most virulent because six differentials out of eight are heavily susceptible to it.

(iii) Next comes race 10, which is more common than the other three.

(iv) Race B is rather poorly represented, having been found only during two years out of six.

(v) Races A and C are both rare and were found only thrice and twice respectively.

The relative prevalence of all the six races is shown in Table LXII.

On completion of this study, the distribution of physiologic races in each of the five areas will be shown in a map.

Table LXI-A

Annual occurrence of Physiologic Races of Puccinia triticina *in area A (the Punjab, Kashmir, N.-W. F. Province, Sind and Delhi), during 1930-37 and the number of times each race was isolated annually*

Race	1930-31 and 1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
10	..., 1	23	4	1	1	2
20	...	1	4	6	11	6
63	1, 1	19	10	10	27	5
A	...	...	...	1	...	...
B	...	...	...	5	2	...
C	...	...	...	1	...	...

TABLE LXI-B

Annual occurrence of Physiologic Races of Puccinia triticina *in area B (the United Provinces and Nepal), during 1930-37 and the number of times each race was isolated annually*

Race	1930-31 and 1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
10	..., 5	21	5	...	...	2
20	...	1	6	16	12	9
63	1, 6	22	21	24	28	30
A	...	...	1	...	...	...
B	...	...	...	1	3	...
C	...	...	...	1	...	...

TABLE LXI-C

Annual occurrence of Physiologic Races of Puccinia triticina *in area C (Bihar, Bengal and Assam), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
10	...	5	...	1	...	2
20	...	...	3	3	2	4
63	1	5	6	6	13	20
A	...	...	...	...	...	...
B	...	...	...	...	1	...
C	...	...	...	...	...	...

TABLE LXI-D

Annual occurrence of Physiologic Races of Puccinia triticina *in area D (Rajputana, Central India and Central Provinces), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
10	...	...	2	1	...	...
20	...	...	3	7	...	2
63	2	...	1	5	...	2
A	...	...	...	...	...	...
B	...	...	...	2	...	...
C	...	...	...	...	...	...

TABLE LXI-E

Annual occurrence of Physiologic Races of Puccinia triticina *in area E (Baroda State, Bombay-Deccan, Hyderabad-Deccan, Mysore State and Madras), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
10	...	7	...	1	1	1
20	...	...	6	3	7	2
63	...	2	9	8	12	7
A	...	...	...	...	1	...
B	...	...	...	2	2	...
C	...	...	...	...	...	...

TABLE LXII

Relative prevalence of Physiologic Races of Puccinia triticina *in the country as a whole during 1931-37 and the number of times each race was isolated annually*

Year	Total number of collections	Races					
		10	20	63	A	B	C
1930-31* ...	15	...	...	2	...	...	...
1931-32 ...		6	...	10	...	...	...
1932-33 ...	77	56	2	48	...	...	...
1933-34 ...	61	11	22	47	1	...	...
1934-35 ...	85	4	35	52	1	10	2
1935-36 ..	96	2	32	80	1	8	..
1936-37 ..	74	7	23	64	...	...	...
TOTAL ...	408	86	114	304	3	18	2

* Only 2 collections were made during 1930-31, both yielded race 63. The study of physiologic races was started in November, 1932.

28. GENERAL DISCUSSION

This rust is also able to oversummer in the uredostage in the hills of India, as stated in previous publications [Mehta, 1925 ; 1929 ; 1931, 1, 2 ; 1933]. There are several species of *Thalictrum* in the hills but none on the plains. As stated before, there is no experimental proof so far of the connection between aecidia reported to occur on *Thalictrum* in this country and the brown rust of wheat. Without repeating the details that have been discussed in the case of black rust, one may safely conclude that the infection of *Thalictrum* also and of wheat therefrom does not take place frequently, if at all, in this country because so far only six physiologic races of this rust have been found.

Waterhouse [1932] got two new races as a result of inoculations on *Thalictrum flavum* with a random collection of teleutospores and stated that these were most probably produced by hybridization on that host.

Regarding mutation in this rust, Miss Roberts [1936] has recorded an important change in the pathogenicity of race 66 under greenhouse conditions. No case of mutation was found during these studies.

On account of the occurrence of *Thalictrum* in the hills, more collections were selected for study from those areas than was necessary so that all races be picked up, as far as possible.

Considering the fact that the area under improved varieties of wheat in this country is very small, it was felt necessary to obtain, as in the case of black rust, as many collections from local (un-improved, *dési* or indigenous) wheats as possible. The object was to pick up all such races to which improved varieties might not be susceptible. The collections obtained were from 50 improved and 278 local wheats, that are grown extensively in different parts of the country, hills as well as plains. A host-wise list of collections from various provinces and states, the number of collections from each host and the races so far found on them are given for the information of the plant breeder in Table LXIII. There is nothing to suggest that a particular variety, on which so far only some of the races have been found, is necessarily resistant to others. It is quite likely that during the course of further studies that are in progress, other races may be collected from some or most of those varieties.

As stated in Part Two, for the country as a whole the real need is a wheat that would resist all the three rusts because by the cultivation of such a variety, only in the hills, it should be possible to effectively cut down the inoculum which is blown to the plains.

TABLE LXIII

Crosses and other varieties of wheat (indigenous and foreign) from which samples of Puccinia triticina *were collected for study during 1930-37 and the Physiologic Races found on each*

Serial No.	Name of variety	Province or state from where the collections were obtained	Total number of collections	Races met with so far
1	Pusa 120 × C. 591 ...	Punjab	1	20
2	Punjab 8A	Punjab and United Provinces...	11	10, 20, 63 and B
3	Punjab 9D ...	Punjab, United Provinces and Bihar	5	20, 63 and B
4	Punjab 17B ...	Punjab	1	10 and 63
5	Punjab C 499 ...	Rajputana	1	B
6	Punjab C 518 ...	Punjab, United Provinces and Rajputana	6	20 and 63

TABLE LXIII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
7	Punjab C 591 ...	Rajputana	1	68
8	C P H 47	Bihar	1	68
9	B K H	Sind	1	10
10	Cawnpore 13 ...	United Provinces and Hyderabad-Deccan	14	10, 20 and 68
11	Pusa 4	Punjab, United Provinces, Bihar, Baroda State and Bombay-Deccan	11	10, 20, 68 and C
12	Pusa 12	United Provinces, Bihar and Bengal	11	10, 20 and 68
13	Pusa 52	Punjab, United Provinces, Bihar, Bengal and Madras	17	10, 20 and 68
14	Pusa 80-5	Bihar and Madras ...	2	10
15	Pusa 101	United Provinces and Bihar ...	3	20 and 68
16	Pusa 111	Punjab, United Provinces and Bihar	4	10 and 68
17	Pusa 112	Punjab and United Provinces...	2	10 and 20
18	Pusa 113	Bihar	1	20
19	Pusa 114	Punjab	2	10 and 20
20	Pusa 165	Punjab and Bihar ...	3	10, 20 and 68
21	A 013	Central Provinces	1	68
22	A 028	Hyderabad-Deccan ...	1	10
23	A 068	United Provinces	1	20 and 68
24	A 088	United Provinces	1	68
25	A 090	Central Provinces	1	20
26	A 115	Central Provinces	1	20
27	E B 76	Central Provinces	1	68
28	J 18	Rajputana	1	20 and 68
29	Bansi 162	Baroda State	1	68
30	Kesar Bearded ...	Punjab	1	10 and 68

TABLE LXIII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
31	Morvi Beardless ...	United Provinces	1	10
32	Lalpissi	United Provinces	1	68
33	Kathia	United Provinces	1	20 and 63
34	Jaipur Wheat ...	Bihar	1	63
35	Bansi	Central Provinces and Hyderabad-Deccan	2	10, 20 and 63
36	Wagia	Baroda State and Madras ...	2	10 and 20
37	Katha Red ...	Bombay-Deccan ...	1	20
38	Khapli	Mysore	1	63
39	Pusa-awnless ...	Madras	1	63
40	Akkigodhumai ...	Madras	1	10
41	Arisigodhumai ...	Madras	1	63
42	Regenerated Defiance ...	Punjab	1	10
43	Durum	Punjab	1	10
44	Reliance	Punjab	1	10
45	Reward Ottawa ...	Punjab	1	10
46	Java	Punjab	1	20
47	Sunset	Punjab	1	20
48	Jubank	Punjab	1	68
49	Calif	Punjab	1	68
50	Federation	Punjab	1	10, 20 and 63
51-104	Local Wheat ..	Punjab (82 different stations)	54	10, 20, 63, A and B
105-113	Local Wheat ...	Kashmir (9 different stations)...	9	10, 20, 63 and B
114	Local Wheat ...	N.-W. F. Province (1 station)	1	20
115-119	Local Wheat ...	Delhi (1 station)	5	10, 20 and 68

TABLE LXIII—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total number of collections	Races met with so far
120-214	Local Wheat ...	United Provinces (84 different stations)	95	10, 20, 63, A and B
215-235	Local Wheat ...	Nepal (13 different stations) ...	21	10, 20, 63 and B
236-262	Local Wheat ...	Bihar (14 different stations) ...	27	10, 20, 63 and B
263-270	Local Wheat ...	Bengal (6 different stations) ...	8	63
271	Local Wheat ...	Assam (1 station)	1	63
272-277	Local Wheat ...	Rajputana (4 different stations)	6	10, 20 and 63
278-279	Local Wheat ..	Central India (1 station) ...	2	10, 20 and 63
280-285	Local Wheat ...	Central Provinces (6 different stations)	6	20 and 63
286-289	Local Wheat ...	Bombay-Deccan (4 different stations)	4	10, 20 and 63
290	Local Wheat ...	Mysore State (1 station) ...	1	63
291-328	Local Wheat ...	Madras Presidency (27 different stations)	38	10, 20, 63 and B

29. TESTS FOR SEEDLING RESISTANCE

As in the case of black rust, a large number of indigenous and foreign varieties of wheat have been tested separately for seedling resistance with pure cultures of each of the races. The differential hosts of black and yellow rusts were also added to that list, so that the plant breeder may have a wider choice for his work.

Results of tests with differential hosts of black and yellow rusts are given in Table LXIV but the reactions of indigenous and foreign wheats will be published at a later date, as a connected account of work on breeding of resistant varieties which has been in progress in co-operation with the Imperial Indian Economic Botanist.

TABLE LXIV

Reactions of the differential hosts of P. graminis tritici *and* P. glumarum *to physiologic races of* P. triticina *met with in India so far*

Serial No.	Name of variety	Races of *P. triticina*					
		10	20	63	A	B	C
	Differential hosts of P. graminis tritici	Types of reactions					
1	Little club	4	4	0-2	4	4	4
2	Marquis	4	4	4	4	4	4
3	Reliance	4	4	3	4	4	4
4	Kota	4	4	0 ;	0 ;	4	0-2
5	Arnautka	2-3	4	2c	4	4	4
6	Mindum	4	4	4	4	4	4
7	Spelmar	2-3	4	4	4	4	4
8	Kubanka	4	4	2-3	0 ;-2	4	4
9	Acme	4	4	0-2	0 ;	4	4
10	Einkorn	0-2	3	3-4	0-1	0-2	0-1
11	Vernal	4	4	4	4	4	4
12	Khapli	4	4	3c	4	4	4
	Differential hosts of P. glumarum						
13	Michigan Amber	4	4	2-3	3-4	4	4
14	Blé rouge d'Ecosse ...	4	4	0-1	3	4	3-4
15	Strubes Dickkopf	4	4	0-2	2-3	4	4
16	Webster C. I. 3780 ...	4	4	0-1	2-3	4	2-3
17	Holzapfels Früh	4	4	4	4	4	4
18	Vilmorin 23	4	4	0 ;	0 ;	4	2-3
19	Heines Kolben	4	4	4	4	4	4
20	Carstens V	4	4	0 ;	2-3	4	4
21	Spaldings prolific	4	4	0-2	4	4	4
22	Rouge prolifique barbu ...	4	4	2-3	4	4	4
23	Chinese 166	4	4	4	4	4	4

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PART FIVE

Physiologic races of *Puccinia glumarum* (Schm.) Eriks. & Henn., yellow rust of wheat and barley

31. Review of literature

Hungerford and Owens [1923] recorded the occurrence of 'Specialized Varieties' within *P. glumarum*. Rudorf [1929] observed that the form of yellow rust on wheat in Germany was different from that found in the United States of America. The actual isolation of physiologic races of this rust was first done by Allison and Isenbeck [1930]. These workers selected ten differentials for the analysis of different races. In the same year, Gassner and Straib [1930] recorded the occurrence of two physiologic races in Western Germany.

Appel [1930] was able to isolate five physiologic races from a number of samples with the help of ten differentials of his own selection.

The study of physiologic races of this rust was standardized by Gassner and Straib [1932], who finally selected nine varieties of *Triticum vulgare* after inoculation experiments on 313 varieties from *Triticum* groups. With the help of these nine differentials, Gassner and Straib were able to identify fourteen physiologic races. For differentiation between races 2 and 3, and 13 and 14 only, these authors included two additional differentials. As a result of further studies, Gassner and Straib [1934, 1] found three new races and transferred one of the two supplementary differentials to the list of 'essentials'. Five more races were added to the previous list by Gassner and Straib [1934, 2] after a study of ninety-five collections from ten different countries of Europe. For this study, the other supplementary differential was also added to the list of 'essentials'.

Bever [1934] recorded the presence of two different races in U. S. A.

In Canada, Newton and Johnson [1936] found races 8 and 18.

Straib [1937, 1] added sixteen more races, bringing the total to thirty-eight, after a study of more collections from Germany, as well as from Turkey, Hungary, Holland, Sweden, Bulgaria, Belgium, France, Argentine, Chile and Afghanistan, etc. These collections were obtained mostly from wheat and some from barley, rye and five wild grasses.

Straib [1937, 2] reported the occurrence of four races of this rust in South America.

32. Differential hosts

For these studies, the differential hosts as selected by Gassner and Straib were used. Petkuser rye, one of the supplementary differentials, was added during the last two years of study. For tests with single spore cultures, the other three

supplementary differentials were also used in the hope of arriving at a further differentiation between some of the races. The full list of differentials is as follows :—

Michigan Amber, Blé rouge d'Ecosse, Strubes Dickkopf, Webster, Holzapfels Früh, Vilmorin 23, Heines Kolben, Carstens V, Spaldings prolific, Chinese 166 and Rouge prolifique barbu. The supplementary differentials are :—Triticum dicoccum tricoccum, Fong Tien (barley), Heils Franken (barley) and Petkuser rye.

38. Rust collections and their analysis

After a preliminary study of nineteen collections and one single spore culture of this rust in India, the writer [Mehta, 1933] pointed out indications of two races out of four, described by Allison and Isenbeck [1930]. So far, 231 collections of this rust from wheat and five from barley have been studied. Out of these, seventy-four were obtained from the hills. Amongst the grasses, this rust was found only once on a species of *Agropyron* but on inoculation it failed to infect wheat or barley and the collection could not, therefore, be analysed. The following races have been met with so far :—13, 19, 20, 31, A, D, E and F. The race formerly labelled here as B is numbered in Gassner and Straib's key as 19 and race C corresponds to No. 31 of Straib's latest list. Races A, D, E and F are new. The range of infection produced by a single spore culture of each of them has been supplied to Dr. Straib for the assignment of International numbers.

Names of places wherefrom collections of this rust were obtained as well as the composition of samples from each locality are shown in Tables LXV-LXXI.

Table LXV

Physiologic Races of Puccinia glumarum *met with in thirty-four samples of yellow rust of wheat and two of barley from the Punjab and Kashmir. (Collections from altitudes* of nearly 3,000-10,000 ft. above sea level, obtained during the years 1931-37)*

Places of rust collections—	1931-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab										
1. Narkunda ...	...; 1	...; A	1	A	1	31	1	19	...	...
2. Mattiana	...	...	1	A	1	A, 31	1	19	...	...
3. Theog	...	...	1	A	...	...	1	A ?, 31	...	...
4. Fagu	...	...	...	...	1	31	...	..	1	A

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

† In addition to clear reactions of race 31, produced by one of the isolations from this collection, types of infection characteristic of this race were produced by the other isolation on all the four differentials infected, but one of them, *i.e.* Chinese 166, showed reaction of race A as well, on some of the leaves. As shown in Table LXXIII, identical reactions are produced by races 31 and A on all the differential hosts excepting Chinese 166.

TABLE LXV—*contd.*

Places of rust collections	1931-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
5. Simla	1 ; ..	A, 19 ;..	1	A	...	...	1	A	1	31
6. Kotgarh ...	...	...	..	..	..	..	2	‡ 19, 31	...	...
7. Kandaghat ...	...	...	...	..	...	...	1	A, 31	1	A
8. Kasauli	..	...	..	...	...	...	1	A	1	A
9. Barog	...	...	1	A	..	...	...	...	...	...
10. Dharmpore ...	...; 1	... ;A	...	...	..	...	1	A	...	..
11. Keylong	..	...	...	...	1	A	...	...	...	..
12. Gindhala	...	...	...	...	1	A, 19	...	...	...	..
13. Pathan Tract ...	...	...	...	...	1	A	...	...	...	...
14. Palampore ...	..	...	...	...	...	...	..	...	1	A ?, 31
15. Kangra	... ;1	... ;A, 19	...	...	...	...	4	A, D	...	...
16. Pokhar	...	..	..	...	..	..	...	...	1	‡ 19
17. Chitrara	...	...	...	...	...	..	...	..	1	31
Kashmir										
18. Banihal	..	...	..	..	...	...	...	...	1	A, E
	1 ; 3	A, 19 ; A, 19	5	A	6	A, 19, 31	13	A, D, 19, 31	8	A, E 19, 31

Total number of collections 36
Races met with ... ... A, D, E, 19 and 31

? In addition to clear reactions of race 31, produced by one of the isolations from this collection, types of infection characteristic of this race were produced by the other isolation on all the four differentials infected, but one of them, i.e. Chinese 166, showed reaction of race A as well, on some of the leaves. As shown in Table LXXIII, identical reactions are produced by races 31 and A on all the differential hosts excepting Chinese 166.

‡ Collections from barley.

Table LXVI

Physiologic Races of Puccinia glumarum *met with in fifty samples of yellow rust of wheat and one of barley from the Punjab, N.-W. F. Province, Sind and Delhi. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1931-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
The Punjab										
1. Koti-Kalka ...	...	...	...	...	...	...	...	..	1	31
2. Kalka	..; 1	...; A	...	...	..	...	...	..	...	...
3. Karnal	... ;1	...; 19	1	A	2	19	3	A	2	A, 19
4. Lahore	...; 1	...; A	...	...	1	31	...	...	...	...
5. Lyallpur	1 ; 1	19; 19	2	A	1	19	8	A, 19 ?, 31	3	† A, 19, 31
6. Hoshiarpur ...	...	...	1	A	...	...	...	..	1	31
7. Gurdaspur ..	1 ; 1	A ; A	1	A	1	31	1	A, 19,	1	A
8. Khanewal ...	...	...	...	..	1	19	1	31	...	...
9. Pathankote ..	..; 1	..; A	...	...	...	...	...	...	..	...
10. Jhelum	...	...	...	...	...	...	...	...	1	31
11. Rawalpindi ...	...	...	1	A, 19	1	A	1	19	1	31
12. Morinda	...	...	1	A, 19	...	...	...	...	...	...
13. Chattar	...; 1	...; A	...	...	...	...	...	...	...	...
N.-W. F. Province										
14. Haripur	...	...	1	A, 19	...	...	...	...	...	...
Sind										
15. Sakrand	...	...	...	...	2	31	...	...	1	A
16. Hyderabad ...	...	..	...	...	1	19	...	...	...	...
Delhi										
17. Delhi	... ;1	..; A	1	31	1	19	...	...	1	19
	2 ; 8	A, 19 ; A, 19	9	A, 19, 31	11	A, 19, 31	9	A, 19, 31	12	A,19, 31

Total number of collections 51
Races met with ... ... A, 19 and 31

? In addition to clear reactions of race A, produced by one of the isolations from this collection, types of infection characteristic of this race were produced by the other isolation on all the three differentials infected, but one of them, i.e. Webster C. I. 3780, showed reaction of race 19 as well, on some of the leaves. As shown Table LXXIII, identical reactions are produced by races A and 19 on all the differential hosts excepting Webster C. I. 3780.

† Collection from barley.

TABLE LXVII

Physiologic Races of Puccinia glumarum *met with in twenty-four samples of yellow rust of wheat from the United Provinces and Nepal. (Collections from altitudes* of nearly 3,000-7,500 ft. above sea level, obtained during the year 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Kumaon Hills										
1. Almora	1	A, 19	...	...	...	...	...	...	...	...
2. Muktesar ...	...	...	1	19	...	..	...	...	...	...
3. Tarikhet	...	...	1	19	...	..	...	...	...	...
4. Bhimtal	..	..	1	A, 19	...	...	...	...	...	...
5. Eastern Kumaon ...	...	...	1	A, 19	1	19	...	...	...	...
6. Jeolikote	1	19	...	...	..	...	...	...	...	..
7. Saiah	1	19	1	A, 19	...	...	...	...	1	A
Nepal										
8. Asurkot	...	...	...	...	...	..	1	A, 31	..	..
9. Tansing	1	A	...	...	...	...	1	A	..	..
10. Piuthan	...	...	...	...	1	31	1	A	...	...
11. Balkot	.	...	..	...	...	...	1	31	...	...
12. Riri	...	...	...	..	...	...	...	...	1	A
13. Wangla	...	...	...	...	...	...	...	...	1	31
14. Malunga	...	...	...	...	...	...	...	...	1	A
15. Galkot	...	...	...	..	...	...	...	...	1	31
16. Bervas	...	...	..	..	.	..	1	A, 19	...	..
17. Ramche	...	...	...	...	...	..	1	31	..	..
18. Budanmara ...	...	...	...	...	...	...	1	31	...	...
19. Sakhi	...	...	...	...	1	31	...	...	...	...
	4	A, 19	5	A, 19	3	19, 31	7	A, 19, 31	5	A, 31

Total number of collections 24
Races met with ... ... A, 19 and 31

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

Table LXVIII

Physiologic Races of Puccinia glumarum *met with in seventy-two samples of yellow rust of wheat and one of barley from the United Provinces. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
1. Dogadda	...	...	...	..	1	A, 19	..	..	1	A
2. Kashipur ...	...	..	.	...	1	31	...	...	...	...
3. Haldwani ...	1	A, 19	1	A, 19	...	...	...	...	...	...
4. Nepalganj ...	...	...	...	...	1	31	...	...	1	31
5. Kotdwara ...	...	...	1	A, 19	...	...	1	31	1	31
6. Mailani	..	...	1	A	1	A	1	31	...	...
7. Pilibhit	1	A, 19	1	A, 19	1	A, 19	...	...	...	...
8. Bareilly	1	A, 19	1	A, 19	2	31	...	...	1	A
9. Chandausi ...	1	19	...	...	...	...	..	...	..	..
10. Nautanwa ..	..	...	...	...	...	...	1	A	...	...
11. Gainsari	...	...	...	...	...	...	1	31	1	19*
12. Dehra Dun ...	1	19	1	A	1	31	1	A, 31	...	...
13. Moradabad ...	...	...	1	A	1	31	...	...	...	...
14. Meerut	1	19	...	...	...	...	...	...	...	...
15. Bulandshahar ...	1	A, 19	..	...	...	...	...	...	...	..
16. Gorakhpur ...	1	A, 19	1	A	2	19, 31	1	19	...	...

* Collection from barley.

TABLE LXVIII—*contd.*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
17. Bellraien	...	..	1	A	1	31	1	19, 31	...	...
18. Gonda	...	..	1	A	1	31	1	A	...	...
19. Bahraich	...	...	...	...	...	...	1	A	...	...
20. Lakhimpur Kheri ..	..	...	1	A, 19	...	...	...	...	...	...
21. Sitapur	...	...	...	...	...	...	1	A	...	...
22. Barabanki ...	1	19	1	A	1	31	1	E	...	...
23. Lucknow ...	1	A, 19	1	A, 19	...	...	...	...	...	...
24. Fyzabad	1	A, 19	1	A	...	...	2	A, 31	..	...
25. Shahjahanpur ...	...	...	1	A, 19	...	...	1	31	...	...
26. Najibabad ...	...	...	1	19	...	...	...	...	...	...
27. Cawnpore ...	1	A, 19	...	...	...	...	...	...	1	31
28. Allahabad ...	1	A	...	...	...	...	...	...	1	A
29. Benares	1	A	...	...	...	...	...	...	1	31
30. Agra	1	A	1	A	...	...	1	19	1	A
31. Jhansi	...	...	1	A	...	...	1	19	1	A
	15	A, 19	18	A, 19	14	A, 19, 31	16	A, E, 19, 31	10	A, 19, 31

Total number of collections 73

Races met with ... ... A, E, 19 and 31

TABLE LXIX

Physiologic Races of Puccinia glumarum *met with in twenty-five samples of yellow rust of wheat from Bihar and Assam. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Bihar										
1. Raxaul	...	...	...	...	..	...	...	...	1	31
2. Jagbani	1	19	...	...	...	...	1	19	...	...
3. Pusa	2	A	1	A	3	31	...	...	1	A, 31
4. Darbhanga ...	...	...	...	...	...	...	...	...	1	A
5. Patna	1	A	...	...	...	...	1	A	1	19
6. Sabour	1	A	...	...	1	31	1	31	...	...
7. Harinagar ...	...	...	...	...	...	...	..	..	1	31
8. Jaynagar ...	...	...	...	...	..	...	1	A	1	A
9. Motihari	...	...	...	...	...	...	1	31	...	...
10. Katihar	1	A	1	19	...	...	...	...	...	...
11. Chapra	...	...	1	A	...	...	...	...	...	...
Assam										
12. Dhubri	...	...	...	...	...	...	...	...	1	31
	6	A, 19	3	A, 19	4	31	5	A, 19, 31	7	A, 19, 31

Total number of collections 25

Races met with ... ... A, 19 and 31

TABLE LXX

Physiologic Races of Puccinia glumarum *met with in thirteen samples of yellow rust of wheat from Rajputana, Central India and Central Provinces. (Collections from the plains and altitudes below 3,000 ft. obtained during the years 1931-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Rajputana										
1. Jaipur	...	...	1	A, 19	2	A, 31	...	...	1	31
2. Ajmer	...	...	...	...	1	31	...	...	...	...
3. Sriganganagar ...	...	...	...	...	...	...	1	E	...	...
Central India										
4. Datia	...	...	..	...	1	19	...	...	...	...
Central Provinces										
5. Saugor	1 ;...	19 ;...	...	...	...	...	1	A ?, 31	..	.
6. Katni	...	...	...	...	1	A	...	...	...	...
7. Jubbulpore ..	...	...	...	...	2	A, 19	...	...	1	19
	1 ;...	19 ;...	1	A, 19	7	A, 19, 31	2	A ?, E, 31	2	19, 31

Total number of collections 13

Races met with ... ... A, E, 19 and 31

? In addition to clear reactions of race 31, produced by one of the isolations from this collection types of infection characteristic of this race were produced by the other isolation on all the four differentials infected, but one of them, i.e. Chinese 166, showed reaction of race A as well, on some of the leaves. As shown in Table LXXIII, identical reactions are produced by races 31 and A on all the differential hosts excepting Chinese 166.

TABLE LXXI

Physiologic Races of Puccinia glumarum* *met with in thirteen samples of yellow rust of wheat and one of barley from Madras. (Collections from altitudes* of nearly 6,000-7,000 ft. above sea level, obtained during the years 1932-37)*

Places of rust collections	1932-33		1933-34		1934-35		1935-36		1936-37	
	No.	Races	No.	Races	No.	Races	No.	Races	No.	Races
Nilgiri Hills										
1. Thambatti ...	..	...	...	...	1	13, 20	...	...	...	...
2. Kilkavatti ...	...	...	...	...	...	...	...	...	1	13
3. Ketti	...	..	1	13	1	13	1	F	1	20
4. Ellenhutti ..	..	..	1	13	..	...	...	...	...	...
5. Kallakorai ...	...	...	...	...	...	...	...	...	1	20
6. Thoddani ...	...	...	...	...	...	...	...	...	1	A
7. Nanjanad ...	...	...	...	...	...	...	...	...	2	†19, 20
8. Kurthukulli ...	...	...	...	...	1	13	...	...	...	...
9. Oodari	1	A	...	..	...	...	...	...	...	...
Palni Hills										
10. Athuvampatti ...	...	...	...	...	...	...	...	...	1	13
	1	A	2	13	3	13, 20	1	F	7	A, 13, 19, 20

Total number of collections 14

Races met with ... ... A, F, 13, 19 and 20

* Information regarding the approximate altitudes of the places mentioned in this table is given in the Appendix.

† Collection from barley.

34. Single spore cultures

A single spore culture of each of the eight races found in this country has been maintained from the time of its isolation. One of these cultures is nearly five years old and had completed its 89th generation by the end of July, 1938. All these cultures are tested on the differential hosts once or twice during the year and their history is given in Table LXXII. The range of infection produced by each of these cultures is shown in Table LXXIII. For the sake of comparison the types of infection given in Gassner and Straib's key [Straib, 1937, 1] are shown in Table LXXIV.

Table LXXII

History of single spore cultures of Puccinia glumarum

Race	Name of station and original host	Stock collection or isolation	Started in	Age in generations	No. of tests made
18	Thambatti-Local ...	Stock	November, 1935	48	4
19	Fyzabad-Local ...	Stock	October, 1933 ...	89	7
20	Thambatti-Local ...	Web (4) ...	December, 1935	47	3
31	Dehra Dun-Local ...	Ch (4) ...	November, 1935	49	6
A	Narkanda-Local ...	Web (3) ...	January, 1934 ...	84	7
D	Kangra-Pb. 17 ...	Spal (2-3) ...	April, 1936 ...	45	5
E	Barabanki-Pusa 4	Web (2-3)-S. Dic (3)	February, 1937 ...	24	3
F	Ketti-Local ...	Pet (3)... ...	January, 1937 ...	25	2

TABLE LXXIII

Range of infection produced by single spore cultures of the different physiologic races of P. glumarum *met with in India so far*

Race	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster C. I. 3780	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Tr. dicoccum tricoccum	Barley: Fong Tien	Barley: Heils Franken	Petkuser Rye
18	4	00	00	3-2	0	0	0	0	i	00	4	4	4	0	0
19	4	0	0	0	0	0	4-3	0	i	00	00	4	4	0	0
20	4	0	0	4-3	0	0	3	0	i	i	i	4	4	0	0
81	4	0	0	2-8	0	0	3	0	i	00	4	4	4	0	0
A*	4	0	0	2-3	0	0	3	0	i	00	00	4	4	0	0
D*	4	0	0	2-8	0	0	3	0	2-3	0	0	4	4	0	0
E*	4	3	2-8	2-8	0	0	4-3	0	i	00	00	4	4	0	0
F*	4	8	2-3	4-3	0	0	3	3	0	0	0	4	4	0	0

* These races are new and have not been recorded in the latest Key by Gassner and Straib [Straib, 1937, 1].

Explanation of symbols as given by Gassner and Straib (1932)

i = immune : leaf completely healthy, no fleck or pustule formation.

0 = highly resistant : no pustule formation, only necrotic flecks or discolouration of the leaf surface.

00 = highly resistant : only a slight discolouration of the leaf on very careful examination, otherwise the leaf appears immune.

1 = resistant : pustules very small in necrotic flecks.

2 = moderately resistant : intermediate between 1-3.

3 = moderately susceptible : uredopustules numerous, spread uniformly over the leaf blade in chlorotic-necrotic flecks.

4 = highly susceptible : uredopustules vigorous and spread uniformly over the entire leaf blade, sometimes with slight chlorosis of leaf surface.

TABLE LXXIV

Types of infection produced by the physiologic races of Puccinia glumarum, *occurring in India, as recorded in Gassner and Straib's Key (Straib, 1937, 1)*

Race	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster C. I. 8780	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Tr. dicoccum tricoccum	Barley: Fong Tien	Barley: Heils Franken	Petkuser Rye
18	4	00	00	3	00	00	0	00	i	i	4	4	2-	00	i (0)
19	4	0	0	0	0	00	4-	0	i	i	i	4	4-	00	i (0)
20	4	0	0	4	0	00	3	00	i	i	i	4	4-	00	i (0)
81	4	0	0	4	00	0	3	0	i	i	4	4	3	00	i (0)

35. Mixtures of physiologic races in nature

Out of 286 collections studied so far, forty-five were mixtures of two races each. Details regarding the composition of these forty-five collections are shown in Table LXXV. Series of inoculations leading to the identification of all the eight races occurring alone are given in Table LXXVI-LXXXIII. In Tables LXXXIV-LXXXVII are shown the details of inoculations that led to the identification of six races from representative combinations. Races D and F were not found in combination with any other race.

General information and summary of data concerning the analysis of 286 collections of *P. glumarum* are given in Table LXXXVIII.

It is essential to point out that considerable difficulties were felt in the isolation of physiologic races from mixtures in the case of this rust. From an examination of the types of infection quoted in Table LXXIII, it would be clear that the separation of races 18, 19, 20 and A respectively, from a mixture with race 31, by the ordinary method of isolation from the differential hosts, can only be accidental. This is due to the fact that the types of infection of race 31 cover entirely those produced by the other four races. Besides, six out of the eleven essential differentials are of little help in the identification of the races mentioned above. There is a large number of possible combinations of these eight races whose separation from mixtures should be very difficult without additional differentials.

Table LXXV

Composition of forty-five collections of Puccinia glumarum *that were found to be mixtures*

Number of combinations	Races	Total number of collections
1	13 and 20	1
2	19 and 31	2
3	19 and A	33
4	31 and A	8
5	A and E	1

TABLE LXXVI

Series of inoculations leading to the identification of Race 13 of Puccinia glumarum

Place and year of collection :—Athuvampatti (Palni Hills, Madras) ; 1937

Host :—Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	7/7 (4)	0/7 (0)	0/7 (0)	7/7 (3-2)	0/8 (0)	0/7 (0)	0/7 (0)	0/8 (0)	0/9 (i)	0/9 (i)	10/10 (4)	0/6 (00)	13
Ch (4)	8/8 (4)	0/7 (0)	0/7 (0)	7/7 (3-2)	0/7 (0)	0/7 (0)	0/7 (0)	0/7 (0)	0/7 (i)	0/7 (i)	8/8 (4)	0/6 (00)	13

TABLE LXXVII

Series of inoculations leading to the identification of Race 19 of Puccinia glumarum

Place and year of collection :- Rawalpindi (Punjab) ; 1935-36

Host :—Wheat "Pb. 8A"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	6/6 (4)	0/5 (0)	0/5 (0)	0/6 (0)	0/7 (0)	0/5 (0)	5/5 (8)	0/8 (0)	0/7 (i)	0/5 (00)	0/6 (0)	0/6 (0)	19
Hein (8)	7/7 (4)	0/5 (0)	0/5 (0)	0/5 (0)	0/6 (0)	0/6 (0)	5/5 (4-3)	0/5 (0)	0/6 (i)	0/6 (00)	0/6 (0)	0/6 (0)	19

TABLE LXXVIII

Series of inoculations leading to the identification of Race 20 of Puccinia glumarum
Place and year of collection :—Kallakorai (Nilgiri Hills, Madras) ; 1937
Host :—Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	7/7 (4)	0/5 (0)	0/9 (0)	5/5 (4-3)	0/7 (0)	0/8 (0)	11/11 (3)	0/8 (0)	0/7 (i)	0/9 (i)	0/8 (i)	0/7 (0)	20
Web (4-3)	7/7 (4)	0/7 (0)	0/7 (0)	7/7 (4-3)	0/7 (0)	0/7 (0)	7/7 (3)	0/7 (0)	0/7 (i)	0/7 (i)	0/7 (i)	0/7 (0)	20

TABLE LXXIX

Series of inoculations leading to the identification of Race 31 of Puccinia glumarum
Place and year of collection :—Kotgarh (Simla Hills, Punjab) ; 1935-36
Host :—Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	7/7 (4)	0/6 (0)	0/7 (0)	6/6 (2-3)	0/6 (0)	0/5 (0)	5/5 (4-3)	0/5 (0)	0/5 (i)	0/6 (00)	6/6 (4)	0/8 (0)	31
Ch (4)	7/7 (4)	0/6 (0)	0/6 (0)	6/6 (2-3)	0/6 (0)	0/6 (0)	5/5 (3)	0/5 (0)	0/4 (i)	0/5 (00)	6/6 (4)	0/6 (0)	31
Hein (4-3)	7/7 (4)	0/6 (0)	0/5 (0)	6/6 (2-3)	0/6 (0)	0/6 (0)	5/5 (3)	0/5 (0)	0/5 (i)	0/6 (00)	5/5 (4)	0/6 (0)	31

Table LXXX

***Series of inoculations leading to the identification of new Race A of* Puccinia glumarum**

Place and year of collection :—Gurdaspur (Punjab); 1936-37
Host :—Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	7/7 (4)	0/7 (0)	0/7 (0)	7/7 (2-3)	0/7 (0)	0/7 (0)	7/7 (3)	0/7 (0)	0/7 (i)	0/7 (00)	0/7 (00)	0/5 (00)	
Hein (8) ...	7/7 (4)	0/7 (0)	0/7 (0)	7/7 (2-3)	0/7 (0)	0/7 (0)	7/7 (4-3)	0/7 (0)	0/7 (i)	0/7 (00)	0/7 (00)	0/5 (00)	A

Table LXXXI

Series of inoculations leading to the identification of new Race D of Puccinia glumarum

Place and year of collection :—Kangra (Punjab); 1935-36
Host :—Wheat "Pb 17"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Fruh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Race
Stock	6/6 (4)	0/5 (0)	0/5 (0)	6/6 (2-3)	0/5 (0)	0/5 (0)	4*/6 (3)	0/5 (0)	4/5 (2-3)	0/5 (0)	0/8 (0)	
Spal (2-3) ...	6/6 (4)	0/5 (0)	0/6 (0)	7/7 (2-3)	0/5 (0)	0/6 (0)	5/5 (3)	0/5 (0)	5/5 (2-3)	0/5 (0)	0/5 (0)	D

* Other leaves showed (0)

TABLE LXXXII

Series of inoculations leading to the identification of new Race E of Puccinia glumarum

Place and year of collection :—Barabanki (United Provinces); 1935-36

Host :- Wheat "Pusa 4"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	8 / 8 (4)	2* / 6 (3)	3* / 7 (2-3)	5 / 5 (2-3)	0 / 7 (0)	0 / 5 (0)	5 / 5 (4)	0 / 6 (0)	0 / 6 (i)	0 / 6 (0)	0 / 6 (0)	0 / 6 (0)	
Web (2-3) ...	8 / 8 (4)	3* / 5 (3)	6 / 6 (2-3)	5 / 5 (2-3)	0 / 7 (0)	0 / 6 (0)	6 / 6 (4)	0 / 6 (0)	0 / 5 (i)	0 / 6 (0)	0 / 5 (0)	0 / 6 (0)	E
Web (2-3)-S. Dic (2-3)	7 / 7 (4)	3* / 5 (3)	3* / 5 (2-3)	5 / 5 (2-3)	0 / 5 (0)	0 / 5 (0)	5 / 5 (3-4)	0 / 5 (0)	0 / 6 (i)	0 / 6 (0)	0 / 7 (0)	0 / 6 (0)	E
Web (2-3)-S. Dic (3) S. S.†	8 / 8 (4)	2* / 6 (3)	3* / 6 (2-3)	6 / 6 (2-3)	0 / 7 (0)	0 / 7 (0)	6 / 6 (3-4)	0 / 5 (0)	0 / 7 (i)	0 / 6 (00)	0 / 7 (0)	0 / 7 (0)	E

* Other leaves showed (0)

TABLE LXXXIII

Series of inoculations leading to the identification of new Race F of Puccinia glumarum

Place and year of collection :—Ketti (Nilgiri Hills, Madras); 1936

Host :– Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	8 / 8 (4)	1* / 6 (3)	2* / 5 (3)	6 / 6 (4)	0 / 6 (0)	0 / 5 (0)	6 / 6 (3)	2* / 5 (3)	0 / 6 (00)	0 / 5 (00)	0 / 5 (00)	1* / 6 (3)	
Pet (3)	7 / 7 (4)	1* / 6 (3)	6 / 6 (2-3)	8 / 8 (4)	0 / 6 (0)	0 / 8 (0)	7 / 7 (3)	2* / 6 (3)	0 / 6 (0)	0 / 7 (0)	0 / 5 (00)	1* / 7 (3)	

* Other leaves showed (0)

† S. S. denotes single spore culture.

TABLE LXXXIII—*contd.*

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Car (8)	7/7 (4)	6/6 (8)	7/7 (2-8)	5/5 (3-4)	0/6 (0)	0/6 (0)	10/10 (8)	4*/6 (8)	0/5 (0)	0/10 (0)	0/6 (0)	0/6 (0)	F
Pet (3) S. S. † ...	7/7 (4)	7/7 (8)	7/7 (2-8)	7/7 (8-4)	0/7 (0)	0/7 (0)	7/7 (8)	4*/7 (3)	0/7 (0)	0/7 (0)	0/7 (0)	0/7 (0)	F

* Other leaves showed (0)
† It seems that the seed of Petkuser Rye contained some impurities.

TABLE LXXXIV

Series of inoculations leading to the identification of Races 13 and 20 of Puccinia glumarum

Place and year of collection:—Thambati (Nilgiri Hills, Madras); 1935
Host:— Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Race
Stock	6/6 (4)	0/5 (0)	0/8 (0)	8/8 (3+)	0/7 (0)	0/6 (0)	2*/6 (3)	0/6 (0)	0/8 (i)	0/8 (00)	7/7 (4)	
Web (3)	6/6 (4)	0/7 (0)	0/6 (0)	7/7 (4-3)	0/7 (0)	0/6 (0)	2*/6 (3)	0/6 (0)	0/7 (i)	0/5 (i)	0/5 (i)	
Local S. S. † ...	5/5 (4)	0/5 (0)	0/6 (0)	7/7 (3-2)	0/7 (0)	0/5 (0)	0/6 (0)	0/7 (0)	0/5 (i)	0/6 (00)	5/5 (4)	13
Web (3)-Web (4) S. S.†	6/6 (4)	0/5 (0)	0/7 (0)	6/6 (4)	0/5 (0)	0/7 (0)	6/6 (8)	0/5 (0)	0/5 (i)	0/5 (i)	0/7 (i)	20

* Other leaves showed (0)
† Local represents Agra local wheat.

TABLE LXXXV

Series of inoculations leading to the identification of Race 19 and new Race A of Puccinia glumarum

Place and year of collection :—Bervas (Nepal) ; 1935-36
Host :—Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Race
Stock	6/6 (4)	0/5 (0)	0/5 (0)	2/6 (2-3)	0/5 (0)	0/8 (0)	7/7 (4-3)	0/6 (0)	0/6 (i)	0/7 (00)	0/6 (00)	
Hein (4-3) ...	6/6 (4)	0/5 (0)	0/6 (0)	0/6 (0)	0/7 (0)	0/6 (0)	7/7 (4-3)	0/5 (0)	0/6 (i)	0/7 (00)	0/7 (00)	19
Web (2-3) ...	6/6 (4)	0/5 (0)	0/5 (0)	6/6 (2-3)	0/7 (0)	0/7 (0)	7/7 (4-8)	0/6 (0)	0/7 (i)	0/7 (00)	0/7 (00)	A

TABLE LXXXVI

Series of inoculations leading to the identification of Race 31 and new Race A of Puccinia glumarum

Place and year of collection :—Pusa (Bihar) ; 1936-37
Host :—Wheat "Local"

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock	7/7 (4)	0/7 (0)	0/7 (0)	7/7 (2-3)	0/7 (0)	0/7 (0)	5/7 (8)	0/7 (0)	0/7 (i)	0/7 (00)	7/7 (4)	0/7 (0)	
Ch (4)	8/8 (4)	0/8 (0)	0/8 (0)	8/8 (2-3)	0/8 (0)	0/8 (0)	8/8 (3)	0/8 (0)	0/7 (i)	0/7 (00)	8/8 (4)	0/6 (0)	31
Hein (8)	8/8 (4)	0/6 (0)	0/7 (0)	8/8 (2-8)	0/7 (0)	0/8 (0)	8/8 (8)	0/8 (0)	0/8 (i)	0/8 (00)	0/7 (00)	0/6 (00)	A

TABLE LXXXVII

Series of inoculations leading to the identification of new Races A and E of Puccinia glumarum

Place and year of collection : *-Banihal (Kashmir)* ; *1937*
Host :—*Wheat "Local selfsown"*

Stock or isolation	Michigan Amber	Blé rouge d'Ecosse	Strubes Dickkopf	Webster	Holzapfels Früh	Vilmorin 23	Heines Kolben	Carstens V	Spaldings prolific	Rouge prolific barbu	Chinese 166	Petkuser Rye	Race
Stock ...	10/10 (4)	2/5 (2)	7/7 (2-3)	5/5 (2-3)	0/9 (0)	0/7 (0)	10/10 (3)	0/7 (0)	0/7 (i)	0/9 (00)	0/6 (00)	0/6 (0)	
Hein (8) ...	7/7 (4)	0/7 (0)	0/7 (0)	7/7 (2-3)	0/7 (0)	0/7 (0)	7/7 (3)	0/7 (0)	0/7 (i)	0/7 (00)	0/7 (00)	0/6 (0)	A
Blé Eco (2) ...	6/6 (4)	9/9 (2-3)	9/9 (2-3)	8/8 (2-3)	0/7 (0)	0/9 (0)	9/9 (4-3)	0/8 (0)	0/8 (i)	0/9 (i)	0/9 (i)	0/6 (00)	E

TABLE LXXXVIII

General information and summary of data concerning 236 collections of P. glumarum *that have been analysed, so far*

I. Number of collections from different hosts and races found on each :—
(i) Wheat . 231 ; . ... Races 18, 19, 20, 31, A, D, E and F
(ii) Barley 5 ; ... ... Race 19

II. Number of collections from hills and hilly tracts of :—
(i) The Punjab, U. P., Nepal and Kashmir 60
(ii) Nilgiri and Palni hills 14

III. Percentage of collections from hills and hilly tracts over ... 31 (74/236)
It might be mentioned that the area under wheat and barley in the hills is less than 5 per cent of the entire acreage under these crops.

IV. Races found in the hills and hilly tracts ... 18, 19, 20, 31, A, D, E and F

V. Races found in the plains ... ... 19, 31, A and E

VI. Composition of collections :—

				Alone	In combination
(i)	Number of collections showing Race	18	...	6	1
(ii)	Ditto	19	...	89	35
(iii)	Ditto	20	...	3	1
(vi)	Ditto	31	...	54	10
(v)	Ditto	A	..	83	42
(iv)	Ditto	D	...	8	..
(vii)	Ditto	E	...	2	1
(viii)	Ditto	F	...	1	..

VII. Out of 236 collections, 45 were mixtures containing two races each.

36. Distribution and prevalence

The information supplied below refers to a period of five years (1932-37) because only four collections were made in 1931-32. The annual occurrence of each of the races in five areas is shown in Table LXXXIX. Races A and 19 were found in all the five areas, the former being more common. Race 31 was met with in collections from the first four areas. Race E was found in the first two areas and the fourth, race 13 in the Nilgiri and Palni hills, races 20 and F only in the Nilgiris and race D in the Punjab alone. The boundaries of the five areas, referred to above, are shown in Map No. 1.

With regard to their prevalence, it may be stated that race A was found every year and in more than half the number of collections. Next comes race 19 and then race 31. The other five are rather rare and F has been found only once. It might be mentioned, that this rust is not found in the plains of Peninsular India, where the range of temperature during winter is much higher than in other parts of the country. In the Nilgiri and Palni hills this rust is fairly common. The relative prevalence of all the eight races is shown in Table XC.

On completion of this study, the distribution of physiologic races in each of the five areas will be shown in a map.

Table LXXXIX-A

Annual occurrence of Physiologic Races of Puccinia glumarum *in area A (the Punjab, Kashmir, N.-W. F. Province, Sind and Delhi), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
13	...	...	..	...	...	...
19	2	3	3	7	6	4
20	...	...	...	...	...	...
31	...	...	1	7	5	8
A	2	9	13	5	12	10
D	...	...	...	...	3	...
E	...	...	...	...	...	1
F	...	...	...	...	...	...

TABLE LXXXIX-B

Annual occurrence of Physiologic Races of Puccinia glumarum *in area B (the United Provinces and Nepal), during 1932-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
13	...	...	...	...	...	...
19	...	15	13	4	5	1
20	...	...	...	...	...	...
31	...	...	...	12	11	6
A	...	18	20	3	10	8
D	...	...	...	...	...	...
E	...	...	...	...	1	...
F	...	...	...	...	...	...

TABLE LXXXIX-C

Annual occurrence of Physiologic Races of Puccinia glumarum *in area C (Bihar and Assam), during 1932-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
13	...	...	...	...	...	...
19	...	1	1	...	1	1
20	...	...	...	...	...	...
31	...	...	...	4	2	4
A	...	5	2	..	2	3
D	...	...	...	...	...	...
E	...	...	...	...	...	...
F	...	...	...	...	...	...

TABLE LXXXIX-D

Annual occurrence of Physiologic Races of Puccinia glumarum *in area D (Rajputana, Central India and Central Provinces), during 1931-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
13	...	...	...	...	...	...
19	1	...	1	3	...	1
20	...	...	...	...	...	...
31	...	...	...	2	1	1
A	...	...	1	4	1	..
D	...	...	...	...	...	...
E	...	...	...	...	1	...
F	...	...	...	...	...	...

TABLE LXXXIX-E

Annual occurrence of Physiologic Races of Puccinia glumarum *in area E (Madras),* during 1932-37 and the number of times each race was isolated annually*

Race	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37
13	...	...	2	3	...	2
19	...	...	...	...	...	1
20	...	...	...	1	...	3
31	...	...	..	...	...	...
A	...	1	...	...	..	1
D	...	...	...	...	...	...
E	...	...	...	...	...	...
F	...	...	...	...	1	...

* *P. glumarum* was found only in the Nilgiri and Palni hills.

TABLE XC

Relative prevalence of Physiologic Races of* Puccinia glumarum *in the country as a whole during 1931-37, and the number of times each race was isolated annually

Year	Total number of collections	Races							
		13	19	20	31	A	D	E	F
1931-32	4	...	3	...	..	2	...	...	...
1932-33	37	...	19	...	...	28	..	...	...
1933-34	43	2	18	...	1	36	...	...	...
1934-35	48	3	14	1	25	12	..	...	...
1935-36	53	...	12	...	19	25	3	2	1
1936-37	51	2	8	3	19	22	...	1	...
TOTAL ...	236	7	74	4	64	125	3	3	1

37. GENERAL DISCUSSION

As stated in earlier contributions [Mehta, 1925; 1929; 1931, 1, 2; 1933], *P. glumarum* is also able to oversummer in the uredostage at higher altitudes (nearly 6,000 feet and above) in this country. For that reason, a much larger number of collections was selected for study from the hills than was necessary from an acreage covering less than 5 per cent of the total area under wheat. The total number of collections of this rust available for study was much smaller than in the case of the other two because it does not occur in the plains of Peninsular India, due to a higher range of temperature than in the Indo-Gangetic plain.

So far, no alternate host of this rust has been found anywhere and, therefore, the question of the production of new races by hybridization does not arise.

With regard to mutation in the pathogenicity of a race, there is no evidence available from the single spore cultures that have been maintained during the course of these studies. Gassner and Straib [1932] recorded the appearance of a mutant of race 9 in the greenhouse.

Further, out of a total of 198 varieties of wheat, from which collections were obtained, as many as 167 were local (un-improved, *désì* or indigenous wheats). As in the case of other rusts, the object of studying a large number of collections from un-improved wheats was to make sure that no such race to which improved wheats

might be resistant, be left out. A host-wise list of collections from various places, the number of collections from each variety and the races met with so far on each of them are shown in Tables XCI and XCII, for the information of the plant breeder. It is quite likely that a race or races which have not so far been met with on a particular variety might be found on it during the course of further studies.

TABLE XCI

Crosses and other varieties of wheat (indigenous and foreign) from which samples of Puccinia glumarum *were collected for study during 1931-37 and the Physiologic Races found on each*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total No. of collections	Races met with so far
1	C P H 47 × P 12-37 ...	Sind	1	31
2	A T 38 × C P H 47 ...	Sind	1	31
3	Punjab 8A	Punjab	11	19 and A
4	Punjab 9D ...	Punjab	1	31
5	Punjab Type 10 ...	Punjab	1	19
6	Punjab 17	Punjab	1	D
7	17 B	Punjab	2	19
8	Punjab C 499 ...	N.-W. F. Province ...	1	19 and A
9	Punjab C 518 ...	Punjab and United Provinces...	4	19, 31 and A
10	Punjab C 591 ...	Punjab	2	A and D
11	Punjab C 690 ...	Punjab	1	19 and 31
12	Lahoul I	Punjab	1	A
13	Cawnpore 13 ...	United Provinces	4	19 and A
14	Pusa 4	United Provinces	2	A and E
15	Pusa 12	Punjab	2	19 and D
16	Pusa 52	Punjab, United Provinces, Bihar and Madras	13	19, 31 and A
17	Pusa 101	Bihar and Rajputana ...	4	19, 31 and A
18	Pusa 122	Punjab	1	A
19	B 80	Bihar	1	31
20	A 013	Central Provinces ...	1	19 and A

TABLE XCI—*contd.*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total No. of collections	Races met with so far
21	A 068	United Provinces	1	31
22	A 088	Central Provinces	1	19 and A
23	J 26	Rajputana	1	31
24	Moradabad ...	Punjab	1	19 and A
25	Mundi-Pissi ...	United Provinces	1	A
26	Umedpur	United Provinces	1	31
27-67	Local wheat ...	Punjab (25 different stations)	41	19, 31 and A
68	Local wheat ...	Kashmir (1 station) ...	1	A and E
69-72	Local wheat ...	Delhi (1 station)	4	19, 31 and E
73	Local wheat ...	Sind (1 station)	1	19
74-143	Local wheat ...	United Provinces (86 different stations)	70	19, 31 and A
144-157	Local wheat ...	Nepal (12 different stations) ...	14	19, 31 and A
158-171	Local wheat ...	Bihar (10 different stations) ..	14	19, 31 and A
172	Local wheat ..	Assam (1 station)	1	31
173-176	Local wheat ...	Rajputana (3 different stations)	4	19, 31, A and E
177	Local wheat ...	Central India (1 station) ...	1	19
178-181	Local wheat ...	Central Provinces (8 different stations)	4	19, 31 and A
182-193	Local wheat ...	Madras (9 different stations) ..	12	13, 20, A and F

TABLE XCII

Varieties of barley from which samples of Puccinia glumarum *were collected for study during 1935-37 and the Physiologic Races found on each*

Serial No.	Name of variety	Province or State from where the collections were obtained	Total No. of collections	Races met with so far
1	Type 4	Punjab	1	19
2-3	Local barley ...	Punjab (2 different stations) ...	2	19
4	Local barley ...	United Provinces (1 station) ..	1	19
5	Local barley ...	Madras (1 station)... ...	1	19

38. Tests for seedling resistance

A large number of indigenous and foreign wheats has been tested separately, for seedling resistance with pure cultures of each of the eight races under reference. The differential hosts of black and brown rusts were also included in the list so that the plant breeder may have a wider choice for his work. Results of tests with differential hosts are given in Table XCIII but a full account of reactions of indigenous and other foreign wheats as well as their crosses will be published on completion of the work on wheat breeding, which is in progress in co-operation with the Imperial Economic Botanist.

Table XCIII

Reactions of the differential hosts of P. graminis tritici *and* P. triticina *to physiologic races of* P. glumarum *met with in India so far*

Serial No.	Name of variety	Races of *P. glumarum*							
		13	19	20	31	A	D	E	F
		Types of reactions							
	***Differential hosts of* P. graminis tritici**								
1	Little club	4	4	0-2	4	4-2	4	4	4
2	Marquis	0	3-2	4	4	0-1	4	4	2
3	Reliance	3-4	4	4	4	3-4	4	4	4
4	Kota	3	3-2	2-3	4	3-2	4	4	4
5	Arnautka	4	4	4	4	4	4	4	4
6	Mindum	4	4	4	4	4	4	4	4
7	Speemar	4	4	4	4	4	4	4	4
8	Kubanka	4	4	4	4	4	4	4	4
9	Acme	4	4	4	4	4	4	4	4
10	Einkorn	4	2-4	4	3-4	0-1	4	3	3
11	Vernal	2-3	0	0	2-3	0	0	4	4
12	Khapli	2-3	0	00	0	0	0	3-4	3

TABLE XCIII—*contd.*

Serial No.	Name of variety	Races of *P. glumarum* 13	19	20	31	A	D	E	F
		Type of reactions							
	Differential hosts of P. triticina								
13	Malakof	4	4	4	4	3	4	4	4
14	Carina	4	0	0	0	0-1	3-4	4	4
15	Brevit	3-2	0	4	3	0	2	4	4
16	Webster	3-2	0	4-3	2-3	2-3	2-3	2-3	4-3
17	Loros	3-2	0-2	3	3-4	0-2	0	4	4
18	Mediterranean ...	3-4	3	2	2-3	2-3	2	4	4
19	Hussar	2-3	2	3	4	2	4	4	4
20	Democrat	3-4	0	2	2-3	1-2	2	4	4

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Summary

Part one

On an average, there are over 33 million acres under wheat and another 8 millions under barley in this country. Amongst the popular wheats of India there is hardly a variety that could be called 'rust resistant'.

Till the year 1932, when these studies were started, no information was available in India regarding the physiologic races of any of the rusts under reference. Considering their distribution in the country as a whole, it was felt necessary to carry out a simultaneous study of all the three rusts of wheat. Whenever available, collections of black and yellow rusts of barley and black rust of some of the wild grasses were also studied. Later on, the black rust of oats, which was found in this country for the first time during these studies, was also added to the programme of work.

The methods employed in these studies are described at length.

Construction of greenhouses with cooling devices, designed by the writer, and other details of equipment are also described.

As far as possible, collections of rusts were obtained from all important parts of the country. For the convenience of reference, the country has been divided into five areas and maps are appended to show the boundaries of each.

The present article deals with the physiologic races of (i) *Puccinia graminis tritici*, (ii) *P. graminis avenae*, (iii) *P. triticina* and (iv) *P. glumarum*.

So far, *P. graminis secalis* has not been found. Rye has been found to be weekly susceptible to *P. graminis tritici*.

Some of the physiologic races of *P. glumarum* on wheat have been found to infect barley and the only race found so far on the latter is able to infect wheat.

Part two

Details regarding the composition of thirty-five samples were published by writer in the year 1933. Since then, 551 collections of black stem-rust of wheat, barley and three wild grasses have been fully analysed. Over 26 per cent of the collections were obtained from the hills. Only six physiologic races, including the four recorded in 1933, have been found to occur in the country, so far. These are 15, 21, 24, 40, 42 and 75. Full information regarding the collections under report has been given in tables.

Each of the six races has been maintained in a single spore culture and the range of infection produced by them is shown in a table. One of the cultures completed its 100th generation by July, 1938. No mutation has so far been noticed.

Out of 586 collections studied since 1932, 163 were mixtures of two races or more.

Race 42 is the most predominant; next comes race 15 which happens to be the most virulent; race 24 is rather rare and 21 has been found only once.

The importance of collections from the hills and from un-improved indigenous varieties is also discussed.

The need of a variety that would resist all the three rusts of wheat for cultivation in the hills has been emphasized. For the information of the plant breeder, tables have been appended to show the races that have so far been found on varieties under cultivation in different parts of the country. Reactions of differential hosts of brown and yellow rusts in the seeuling stage have also been given in a table.

Part three

Black rust of oats was found in this country for the first time during these studies. So far, it has not been reported from any other part except the Nilgiris. Only ten collections have been studied and the races met with are 3, 4, 6 and 7.

Full information regarding the composition of the samples analysed, range of infection produced by each race in a single spore culture and the races found in mixtures is supplied in tables.

Part four

Details regarding the composition of fifteen samples of brown rust of wheat were published by the writer in the year 1933. Since then, 393 collections of this rust, including 111 from the hills and hilly tracts, have been analysed. In all, six physiologic races, including the two previously recorded, have been found so far. These are 10, 20, 63, A, B and C. The last three have not been reported from any other country.

The importance of collections from the hills has been emphasized.

Each of the six races has been maintained in a single spore culture and two of these cultures had completed their 100th generation by July, 1938. No mutation has so far been noticed.

Out of 408 collections of this rust that have been studied so far, 117 were mixtures of two races or more.

Race 63 is the most predominant; race 20 comes next and this happens to be the most virulent; race 10 is more common than the other three, whereas races A and C were found only thrice and twice respectively.

Details of collections from improved as well as local wheats are supplied in tables. Reactions of differential hosts of black and yellow rusts in the seedling stage have also been given in tables for the information of the plant breeder.

PART FIVE

So far, 286 collections of yellow rust, including seventy-four from the hills, have been studied. The races found are 18, 19, 20, 81, A, D, E and F. The last four are new. Out of these eight, only race 19 has been obtained from barley.

All the races have been maintained in single spore cultures and one of them had completed its 89th generation by July, 1938. No case of mutation has been noticed.

Out of 236 collections, 45 were found to be mixtures of two races each.

Races A and 19 are fairly well distributed; race 31 comes next; the other six races are more or less restricted in their distribution.

The importance of collections from the hills has been emphasized.

For the information of the plant breeder, details of collections from improved as well as local wheats have been supplied. Reactions of differential hosts of black and brown rusts in the seedling stage have also been given in a table.

APPENDIX

Approximate altitudes of places in the hills and hilly tracts (altitudes of 2,000–10,400 feet above sea level) wherefrom collections of rusts were obtained

Serial No.	Name of place	Altitude
	THE PUNJAB	
	Simla Hills	
1	Narkunda	9,200
2	Kotgarh	6,500
3	Mattiana	7,900
4	Theog	7,500
5	Fagu	8,200
6	Kufri	8,200
7	Simla	7,000
8	Kandaghat	4,700
9	Solon	4,900
10	Kasauli	6,500
11	Barog	5,000
12	Dharampur	4,800

APPENDIX—*contd.*

Serial No.	Name of place	Altitude
	THE PUNJAB—*contd.*	
	Dhaola Dhar Range	
13	Lahaul	10,000
14	Keylong (Lahaul)	10,400
15	Gindhala (Lahaul)	10,000
16	Pathan Tract (Lahaul)	10,000
17	Manali	6,300
18	Palampore	3,700
19	Kangra	3,000
20	Dalhousie	6,700
21	Pokhar (near Dalhousie)	5,500
22	Chitrara (near Dalhousie)	7,000
	Murree Hills	
23	Murree	6,500
24	Companybagh (near Murree)	5,000
25	Ghoragali (near Murree)	6,000
	KASHMIR	
26	Batote	5,000
27	Banihal	6,500
28	Chapnari (near Banihal)	6,500
29	Vernag	6,000
30	Martand	6,000
31	Ganeshpura (near Pahalgam)	6,500
32	Pahalgam	7,500
33	Fisalna (near Pahalgam)	6,500
34	Avantipur	5,200
35	Srinagar	5,250

APPENDIX—*contd.*

Serial No.	Name of place	Altitude
	KASHMIR—*contd.*	
36	Ikhrajpura (near Srinagar)	5,200
37	Shalabag (near Srinagar)	5,500
38	Kangan (near Srinagar)	6,500
39	Pattan (near Srinagar)	5,200
40	Baramula	6,000
41	Sopore (near Baramula)	5,500
42	Bawa Rishi (near Gulmarg)	7,200
	N.-W. F. PROVINCE	
43	Abbotabad	4,000
44	Mansehra	3,500
	BALUCHISTAN	
45	Quetta	5,500
	UNITED PROVINCES *Kumaon Hills*	
46	Eastern Kumaon (several places)	3,500—5,000
47	Jeolikote	4,000
48	Champawat	5,800
49	Bhimtal	4,500
50	Naukuchia (near Bhimtal)	5,000
51	Tarikhet	5,000
52	Bageswar	3,200
53	Someswar	4,700
54	Almora	5,500
55	Muktesar	7,500

APPENDIX—*contd.*

Serial No.	Name of place	Altitude
	UNITED PROVINCES—*contd.*	
	Chakrata Hills	
56	Chakrata	6,500
57	Saiah (near Chakrata)	4,000
58	Lansdowne	6,000
	NEPAL	
59	Asurkot	5,000
60	Nawakot	5,000
61	Khilchi	5,000
62	Tansing	5,000
63	Piuthan	5,000
64	Balkot	4,500
65	Riri	3,000
66	Wangla	5,000
67	Malunga	5,000
68	Galkot	5,000
69	Sanachidki	3,000
70	Pipari	4,000
71	Sallyana	5,000
72	Sishni	3,500
73	Bervas	5,000
74	Ramche	4,000
75	Budanmara	4,500
76	Sakhi	5,000
	RAJPUTANA	
	Aravalli Hills	
77	Mount Abu	4,000

APPENDIX—*contd.*

Serial No.	Name of place	Altitude
	BOMBAY-DECCAN	
	Western Ghats	
78	Old Mahableshwar	4,500
79	Mahableshwar	4,500
80	Sambarsari (near Mahableshwar)	3,900
81	Western Ghats (several places in Nasik District)	2,000—3,000
82	Waghamba (Nasik District)	2,500
83	Babulana (Nasik District)	3,000
84	Bej (Nasik District)	2,000
85	Babkhera (Nasik District)	2,500
86	Visapur (Nasik District)	2,000
87	Wani (Nasik District)	2,000
88	Singarwari (Nasik District)	2,200
89	Pohali (Nasik District)	2,000
90	Mulher (Nasik District)	2,000
91	Gokul (Nasik District)	2,500
92	Kharad (Nasik District)	2,400
93	Deola (Nasik District)	2,000
94	Deothan (Nasik District)	2,000
95	Anantapur (Nasik District)	2,000
96	Dangs	2,500
97	Chinchali (Dangs)	2,000
	MADRAS	
	Nilgiri Hills	
98	Thambatti	6,600
99	Kilkavati	6,500
100	Ketti	6,700
101	Ellenhatti	6,500

APPENDIX—*contd.*

Serial No.	Name of place	Altitude
	MADRAS—*contd.*	
	Nilgiri Hills—contd.	
102	Hoobathalai	6,500
103	Kallakorai	6,700
104	Thoddanni	6,700
105	Anikorai	6,600
106	Coonoor	7,500
107	Ootacamund	7,500
108	Adashola	7,000
109	Nanjanad	7,000
110	Manjidala	6,500
111	Itbilar	7,000
112	Davani	6,500
113	Kurthukulli	6,500
114	Oodari	6,200
115	Fingerpost	7,000
	Palni Hills	
116	Kodaikanal	8,000
117	Kookal	6,000
118	Vilpatti	6,500
119	Lourudupuram	6,700
120	Mannavanur	6,300
121	Athuvampatti	6,500
	Eastern Ghats	
122	Pottangi (Agency Tract)	3,000—3,500
123	Kolla-Malai Hills (several places)	3,000—4,000
	MYSORE STATE	
124	Bangalore (Hebbal Farm)	3,000

SECTION II.—ROLE OF ALTERNATE HOSTS

(With Plates VI-XII, one map and one text-figure)

CONTENTS

Part One: General

Part Two: Rôle *Berberis*

Part Three: Rôle of *Thalictrum*

Summary

PART ONE

General

1. Introduction

In India, *Berberis* and *Thalictrum*, the alternate hosts of *P. graminis* Pers. (black stem-rust of cereals and grasses) and *P. triticina* Eriks. (brown rust of wheat) respectively, are restricted to the hills.

During a study of the annual recurrence of rusts of wheat and barley in the plains of India, which was started by the writer in the year 1923, several visits were paid to Kumaon and Simla hills to make sure, if the initial outbreaks of black and brown rusts of wheat started from their alternate hosts.

In the course of that study, the writer felt that, for further information regarding the rôle of uredospores oversummering in the hills as well as for experimental work on alternate hosts in a tropical country like India, a laboratory in the hills, where alone those plants live, was absolutely essential. In the year 1930, two laboratories were started in the hills, one at Simla (nearly 7,000 ft. above sea level), and the other at Almora (5,500 ft. above sea level) and a small temporary staff was also engaged to assist the writer in these studies. The laboratory at Almora was closed down in the year 1933 but investigations are still in progress at Agra and Simla.

The present article gives a detailed account of experimental work with some of the more common species of *Berberis* and *Thalictrum*, carried out during the last five years. The writer's views, based on fifteen years' study of different aspects of the hitherto unsettled rôle of these plants in annual outbreaks of black and brown rusts of wheat in India, have also been fully discussed.

The writer wishes to express his warm appreciation of the valuable assistance rendered, since the year 1930, by Mr. R. Prasad, M.Sc., at present working as Assistant Mycologist in the scheme of Investigations on Cereal Rusts.

2. Scope of the present investigation

The occurrence of aecidia of *P. graminis* on *Berberis* in this country was first recorded by Barclay [1887], later by Butler and Hayman [1906], Butler and Bisby [1931] and Arthur and Cummins [1933], but there is no experimental evidence of their connection with the black rust of wheat, i.e. *P. graminis tritici*.

Butler [1918] observed that the barberry aecidiospores in Kumaon could not be got to infect wheat and probably belonged to some other race of the parasite. The writer [Mehta, 1929; 1931; 1933] recorded that inoculations made with aecidiospores from barberries in the hills on wheat and barley seedlings, even on

the spot, gave negative results and that most of the aecidial material occurring on barberries belongs to *Aecidium montanum* Butl.

During the course of these studies, *Aecidium montanum* Butl. has been very commonly found on *B. lycium*, *B. aristata*, *B. coriaria* and *B. petiolaris* syn. *B. vulgaris*, var. 1. *vulgaris* proper. Only in the case of *B. lycium*, a specimen collected in May, 1933, was provisionally identified by Sir Edwin J. Butler as belonging to *P. graminis*. The specimen, as stated by Dr. Butler, did not quite agree with the European material of *A. berberidis* Gmel., the aecidial stage of *P. graminis* Pers.

In the light of these facts and having obtained successful germination of teleutospores in April, 1933, the writer felt the need of an experimental study to find out which of the more common species of *Berberis*, occurring in this country, are susceptible to infection by sporidia of black rust of wheat.

With regard to the alternate host of *P. triticina*, the brown rust of wheat, it might be mentioned that Jackson and Mains [1921] obtained successful infection only on some species of *Thalictrum*, as a result of inoculation experiments on a large number of genera with its sporidia.

In this country, Barclay [1887] found aecidia on *Thalictrum javanicum* and *T. minus*. Butler and Bisby [1931] remarked that both the species described by Barclay probably belonged to *Aecidium urceolatum*. Arthur and Cummins [1933] identified the aecidial material collected by R. R. Stewart on *T. minus* and another species of that genus from Chamba and Kashmir as *Puccinia Rubigo-vera* (DC.) Wint.

As in the case of *Berberis*, there is no reference in literature, based on experimental work, indicating that any of the specimens reported to occur on *Thalictrum* is connected with the brown rust of wheat.

In a previous article [Mehta, 1933], it was stated that several inoculations were made during 1931-33 on wheat with aecidiospores occurring in nature near Simla on *T. javanicum* but the results were negative.

Germination of the teleutospores of brown rust, which are very scarce, was obtained, for the first time in January, 1934, in the case of material found on self-sown plants in November, 1933, near Simla. This material was frozen for 12 days in a refrigerator. After having obtained germination of the teleutospores it was felt necessary to carry out whatever experimental work was possible, with the scanty material occurring in nature or formed in the miniature plots during cold weather, in order to find out which of the more common species of *Thalictrum* are susceptible to sporidia of brown rust.

It is necessary to point out that the scope of this investigation was limited, from the start, to include only those species of *Berberis* and *Thalictrum* on which occurrence of aecidia had previously been reported from this country. In the case of a tropical country like India, experimental work on the alternate hosts, mentioned above, is not possible in the plains, due to unfavourable weather, for

more than a couple of months in any year, i.e. December-January. Even at a place like Simla, nearly 7,000 ft. above sea level, this work cannot be done for more than 5-6 months in the year and that too after artificial cooling of the green-house. For this reason and also because of simultaneous studies of physiologic races of four different rusts, their oversummering in the hills, initial outbreaks and incidence in the plains, as well as the maintenance of single spore cultures, cross-inoculations, etc. and limited staff, it was not possible to undertake inoculations on the less common species of alternate hosts. Besides, it is very difficult to obtain reliable seed or root-wood of *Berberis* from correctly identified plants.

Parker [1918] stated that species of *Berberis* are variable and closely allied. Similarly, Levine and Cotter [1932] observed that several specific and varietal names of *Berberis* are synonymous and that these synonyms are sometimes puzzling and conflicting. Also, that the barberry nomenclature has been a vexing problem to the plant pathologist. The identification of the species of this genus, therefore, is best done by a specialist. Besides, some of the species of this genus have a very restricted distribution in this country and others grow at places very difficult of access, except to a party well-equipped for purposes of collection.

3. Material and methods

For experimental work with sporidia of *P. graminis tritici*, seed of *Berberis vulgaris* Linn. was collected by the writer at Cambridge in the year 1930. Later on, more seed and root-wood of this species was obtained from the same place. Some seed was also received from U. S. A. This species, being the most susceptible to black rust, was always used as a control in the earlier part of the study. Later on, in some of the experiments, *B. lycium* (indigenous) that was found to be moderately susceptible was occasionally inoculated as a control. Inoculations were also made on *B. aristata*, *B. umbellata* ? (Swiss), *B. petiolaris*, formerly known as *B. vulgaris*, var. 1, *vulgaris* proper. *B. coriaria*, a species very common at higher altitudes in the Simla hills, was added to the list although no aecidia of *P. graminis* have been recorded to occur on it by Butler and Bisby [1931].

For experimental work with sporidia of *P. triticina*, seed of *Thalictrum flavum* (foreign), which does not occur in India, was obtained from Switzerland. It might be mentioned that this species was found to be the most susceptible to brown rust by Jackson and Mains [1921]. In addition, seed of *T. minus* found in India also and *T. Delavayi*, not known to occur in this country, was obtained from Switzerland. The other seed obtained from that country was that of T. *aquilegifolium* and *T. polycarpum* but it did not germinate. From amongst the indigenous species, *T. javanicum*, *T. foliolosum* and *T. neurocarpum* were selected for study. For all inoculation experiments, *T. flavum* was used as a control.

In view of the fact that seed of some of the species of *Berberis* and *Thalictrum* had been obtained from temperate regions and some of the indigenous species

transplanted from altitudes higher than that of Simla, all plants were kept under a balcony or in a glazed verandah with open windows and protected from direct sun. In spite of that, a large number of seedlings and even older plants of *B. vulgaris* Linn. died every year, during summer. *B. umbellata* ? (Swiss) did not flourish either and all the six plants raised from its seed in 1934-35 died one by one, by the summer of 1938. In the case of *B. petiolaris* also, transplanted from Narkunda (nearly 9,000 ft. above sea level), several plants died every year.

In order to obtain fresh leaves at different times during November-March, all the older plants of *Berberis* were cut back in September-October. Seed of different species, whenever available, was sown off and on, in order to get a frequent supply of fresh leaves, as required for inoculations.

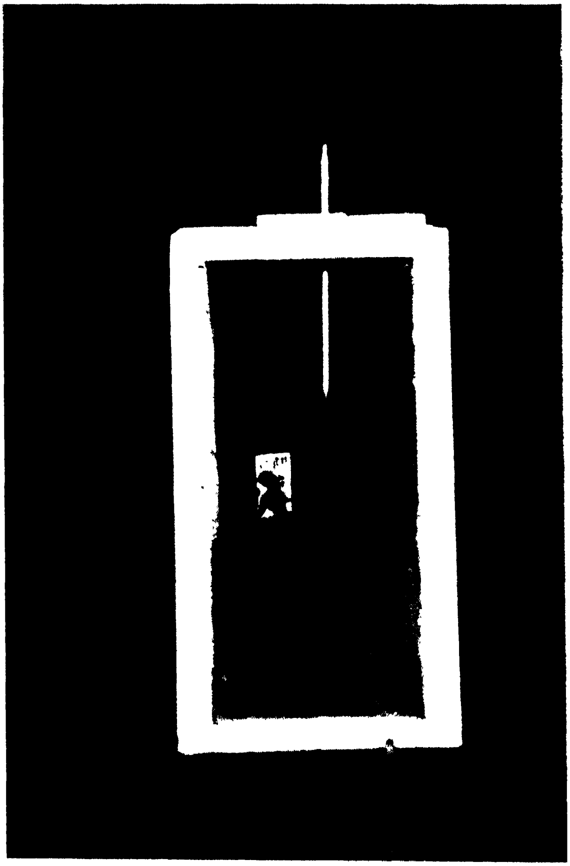
The teleuto-material of both the rusts, used in these studies, was mostly raised from year to year in miniature plots inoculated during July-August at Simla and allowed to remain under natural conditions till following March, or collected from self-sown plants during winter. In the year 1938, due to very meagre formation of teleutospores of brown rust at Simla, the material formed in November, 1937, on the first crop (sown June-July) in the Palni hills had to be used.

Except occasionally in the case of brown rust, only such material was used for inoculations as showed over 50 per cent germination. Ordinarily, germination was found to be much higher, i.e. 60-90 per cent. Material showing less than 30 per cent germination was never used for this work.

Before inoculation, each pot was kept in a small saucer containing water and covered for 6-8 hours with a glass case, heavily sprayed with water. All inoculations were made late in the afternoon, with a platinum loop dipped in a suspension of germinating teleutospores. After inoculation, each pot was covered with a lantern chimney and pieces of straw or a leaf (in the case of brown rust) bearing teleutosori were hung by a thread over the fresh leaves and the top of the chimney closed with a petri-dish, the inside of which was lined with wet filter-paper. The pot, with the chimney in tact, was further covered with a glass case provided with a lid and resting on moist sand-bed in a tray. The interior of the glass case was sprayed, through the hole on the top, several times in the day. The interior of the chimney was gently sprayed with water and the petri-dish slightly shaken from time to time. On the 4th day, the pots were taken out from the glass case and chimney, and placed on the greenhouse bench.

In order to be sure of the age of leaves selected for inoculations with teleutospores from a suspension, every fresh leaf was marked with a tagged label bearing the date, as soon as it showed signs of unfolding.

In general, the procedure adopted for incoulations was the same as recommended by Cotter [1932] and Newton and Johnson [1932]. No inoculations were made with single sporidia.



A glass case used for covering *Berberis* plants during the incubation period. Inside the case, a cooling cylinder, perforated on the sides and base, which was kept filled with ice during the day, and a thermometer are also seen.

The cool green house at Simla showing double glass walls and roof with a space between the two walls. One of the *khus* boxes covered with muslin, the watering tank above it and three *khus* windows are also seen.

4. Equipment

In the absence of a cool greenhouse, all inoculations on *Berberis* and *Thalictrum* had to be made in a glazed verandah, during the first year of this work, i.e. the winter of 1933-34. On sunny days, it was found that during the course of several experiments, temperature exceeded the range, most favourable for the infection of these hosts. The teleutospores used in these experiments invariably showed good germination and although the air around the plants was cooled with cylinders full of ice, as shown in Plate VI, the inoculated plants showed poor infection and, in some cases, no infection at all. This was evidently due to unfavourable range of temperature, during the incubation period.

Keeping in view the fact that on sunny days, even during winter, the interior of the greenhouses at Simla, in use for the study of physiologic races had to be cooled, it was felt necessary to construct a greenhouse for work on alternate hosts with double walls and roof, in order to lower temperature still further. A photograph of this greenhouse, specially designed by the writer for this study, is shown in Plate VII and its section in Fig. 3. Between the two walls, made of Belgian sheet glass, a space of 4 in. was provided in each section and there was a similar space between the two sheets of the roof. A full-length chimney at the top was also constructed for the exit of hot air from each of the sections of all the four walls as well as from the interior of the greenhouse. In order to keep out wind-borne infection, a double muslin ceiling, with a space of 1½ in. between the two folds, was inserted below the roof all round. Cool air was introduced into this greenhouse with the help of two ventilating fans and *khus* boxes as described in Section I. A *khus* screen was also inserted in each of the windows, in order to cool the air entering the space between the two walls of each of the sections. These screens were kept wet on sunny days, whenever needed.

By these means, it was found possible to control the temperature of this greenhouse within a range of 50°-65°F., during the day, for as many as five months, i.e. November-March each year. A thermograph was always kept in the greenhouse for a constant record of temperature. If steadily rising above 65°F. it was found necessary to regulate temperature with the help of iced-water for wetting the *khus* boxes. During the night and on such days when there was snow outside, all the glass windows were closed and the greenhouse heated with a petroleum stove, connected with a separate chimney for the exit of smoke and fumes through the double wall of one of the sections. In order to maintain a fair amount of humidity inside the greenhouse at night, its floor was freely watered every evening. The use of wet *khus* boxes and screens during the day helped a great deal to keep the air sufficiently moist. Judging from the nature of infection on the susceptible species, the conditions inside the greenhouse appeared to be most congenial.

5. Acknowledgments

1. The writer is very grateful to Prof. F. T. Brooks, F.R.S., University of

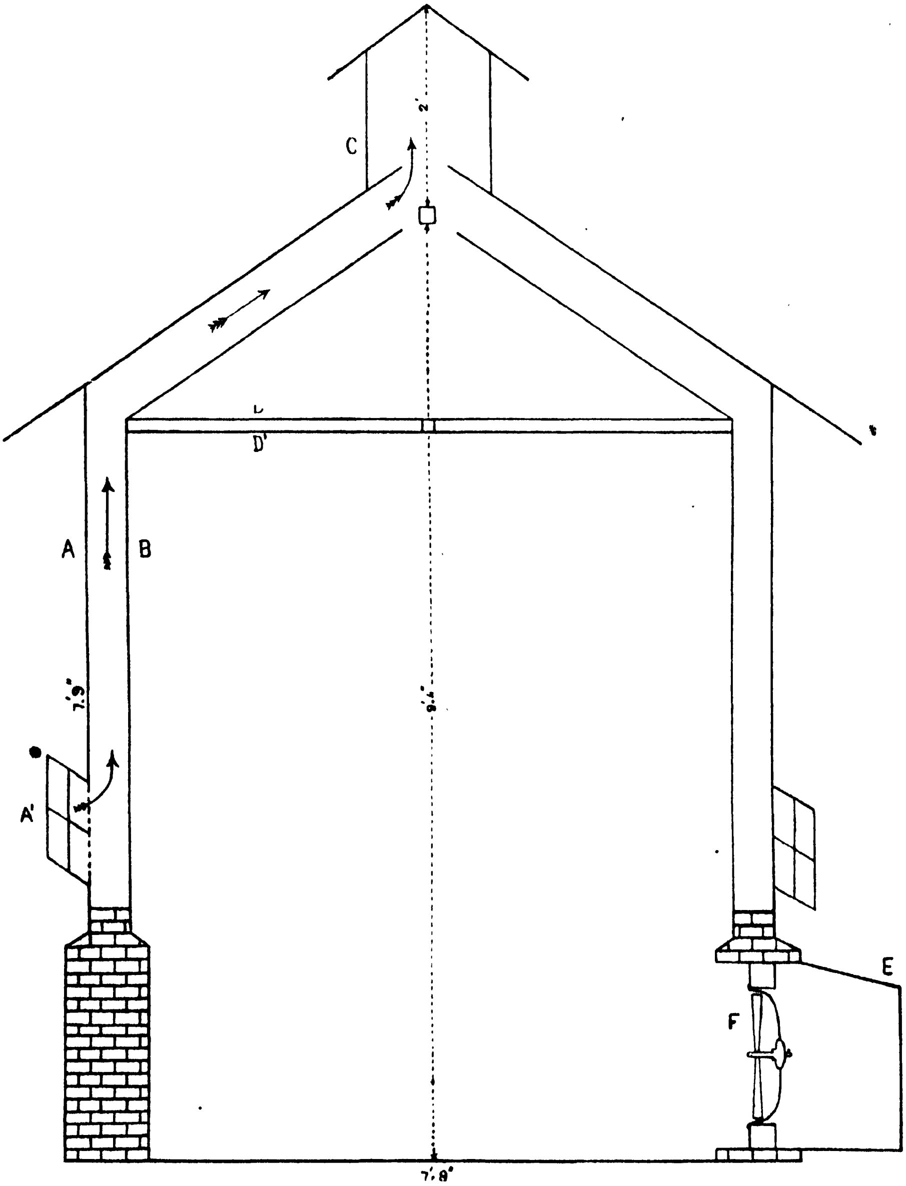


FIG. 8. A section of the cool greenhouse. A, outer glass-wall, A' window; B, inner glass-wall; C, full-length chimney; D and D' two folds of the muslin ceiling; E, *khus* box and F, ventilating fan.

Cambridge ; Sir Edwin J. Butler, F.R.S., Agricultural Research Council, London ; Prof. E. C. Stakman, University of Minnesota ; Prof. A. H. R. Buller, Manitoba ; Drs. J. H. Craigie and M. Newton, Rust Research Laboratory, Winnipeg, for helpful interest in the investigations under report.

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3. The writer also desires to record his appreciation of the help rendered by Messrs. R. Prasad and D. D. Gupta in the tabulation of data for this section.

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PART TWO

Rôle of Berberis

7. Review of literature

In some of the recent publications including a monograph by Lehmann, Kummer and Dannenmann [1937], an historical review of the rôle of *Berberis* in the life-history of *P. graminis* Pers. in different countries has been fully discussed. It is unnecessary, therefore, to refer in detail to the classic researches of de Bary on the subject or to contributions made by other workers in the earlier part of this century. Referring only to contemporary work, it may be stated that the occurrence of aecidia on *Berberis* has been reported from almost every country where this host is found.

In India, Barclay [1887] recorded, for the first time, presence of aecidia on barberries in the Simla hills during August but he did not confirm their genetic relationship with black rust of cereals or grasses. Butler [1903] stated that the aecidium occurring on *Berberis* at Mussourie (Siwalik range, India) is not allied to the fungus on wheat. He further observed that the barberry may be entirely left out of account in India and that it was questionable if true barberry aecidium belonging to black rust existed in this country.

On the other hand, Freeman and Johnson [1911], Stakman and Piemeisel [1917], Gussow [1913], Lind [1913], Broadbent [1921] and others pointed out a definite connection between the aecidium on barberry and distribution of black rust on graminaceous hosts in the United States of America, Denmark and the British Isles, respectively.

After a detailed study of the recurrence of rusts in the neighbourhood of Cambridge, the writer [Mehta, 1923] stated that annual outbreaks of black rust could be explained only by fresh infection through aecidiospores produced on barberry. Stakman, Kempton and Hutton [1927] stated that hundreds of local epidemics extending from 1-5 miles from barberry bushes had been observed and carefully mapped in U. S. A. Peltier and Thiel [1927] have also reported the infection of barberries at one time or another throughout the State of Nebraska.

Infection of cereals by aecidiospores from barberries has been recorded in the Amur region U. S. S. R. by Shitikova-Roussakova (1927). Waterhouse [1934] reported a case of natural infection of *Berberis* in Australia.

Bulter and Bisby [1931] recorded the occurrence of aecidia of *P. graminis* Pers. on *Berberis vulgaris*, *B. aristata*, *B. lycium* and *B. umbellata* in the Himalayas and Arthur and Cummins [1933] identified the aecidial material collected by R. R. Stewart on *B. pseudumbellata* from Tangmarg, Kashmir, as *P. graminis* Pers., but there is no experimental evidence of their connection with the black rust of cereals

8. Germination of teleutospores

A large number of germination tests were made during the years 1930-32 with teleutospores collected from wheat and barley crops at Almora and Simla, in May-June. After collection, the material was kept in the open and exposed to natural conditions till the close of winter. As tried by Thiel and Weiss [1920], teleutospores were treated with chloroform vapour for one minute and immersed in 1 per cent citric acid for 15 minutes before every test but no germination took place. Some of the collections of teleutospores were wetted and dried alternately, several times, and then floated for prolonged periods on distilled as well as tap-water, as recommended by Maneval [1922] but the results were negative.

Having failed in these attempts, the method adopted by Johnson [1931] was also tried with several collections. Straw bearing teleutosori was frozen in a refrigerator for 2-10 days and then thawed. After thawing, the material was sprayed with cold tap-water at 5°-10°C. for a week and then dried and wetted alternately for 2 days but there was no success even after 10 or 15 and, in some cases, as many as 20 dryings and wettings. The period of freezing was also prolonged to as much as 30 days, in some tests, but with no success.

Considering the inhibitory effect of higher temperatures on cereal rusts in general, it was felt necessary to raise teleuto-material for inoculations on alternate hosts, during a cooler part of the year, i.e. early in winter. Wheat seedlings were, therefore, raised in miniature plots at Simla and inoculated with uredospores of black rust during July-August, 1932. On these plants, the teleuto-stage appeared in November-December and was allowed to remain under natural conditions till the following spring. Having been exposed to snow, this material showed nearly 20 per cent germination without artificial freezing, in April, 1933. The teleuto-stage of this rust was, therefore, artificially produced from year to year in miniature plots during early winter and inoculations on barberries were made mostly with such material, because it gave as much as 60-90 per cent germination after freezing for 2-10 days.

9. Inoculation experiments

During the period under report, a large number of inoculations was made with sporidia of *P. graminis tritici*, simultaneously on all the species of *Berberis* mentioned below. *B. vulgaris* Linn. (foreign) was used as a control in all the experiments during the years 1933-36. After that, *B. lycium*, an indigenous species that was found to be moderately susceptible, was occasionally inoculated as a control, if suitable leaves of *B. vuglaris* Linn. were not available at the time of the experiment.

All experiments were carried out in the cool greenhouse, the temperature of which, as stated in Part One, was controlled within a range of 50°-60°F. Results

of inoculation experiments, carried out up to the end of March, 1938, are shown in Tables I-XI and photographs of leaves of such species as developed aecidia in Plates VIII-X.

Aecidiospores from every species that developed aecidia were put on wheat and barley and, as expected, they got infected in every case, producing the uredostage of black rust.

TABLE I

Summary of results of inoculations made from time to time, on Berberis vulgaris *Linn. (raised from foreign seed) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed.
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	1	1	1	1	Heavy
3	6	6	6	6	,,
4	2	2	2	2	,,
5	5	5	5	5	,,
6	3	3	3	3	,,
7	18	18	18	18	,,
5—7	152	135	100	133*	,,
10	13	13	13	13	,,
12	35	35	35	35	,,
14	29	None	...	...	No infection
16	24	,,	...	...	,,
18	6	,,	...	...	,,
20—22	55	,,	...	...	,,

* Evidently, aecidia appeared on some of the leaves on which no nectar was mixed, due to coalescence of spermogonia lying side by side because of mass inoculations with sporidia, as stated under Material and Methods.

A

Leaf of *Berberis vulgaris* Linn. (foreign) seven days old at the time of inoculation ×10

B

Leaf of *Berberis lycium* Royle, seven days old at the time of inoculation ×6

Photographs of leaves of *Berberis* showing aecidia formed as a result of inoculation experiments

Photograph of a leaf of *B. aristata*, one day old at the time of inoculation, showing aecidia $\times 10$

Berberis coriaria, leaves 2-3 days old at the time of inoculation, showing aecidia ×10

TABLE II

Summary of results of inoculations made, from time to time, on Berberis lycium *Royle (plants raised from seed) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	14	14	14	14	Moderate
3	16	16	16	16	Moderate to heavy
4	5	5	5	5	Heavy
5	18	18	18	18	Moderate to heavy
6	1	1	1	1	Moderate
7	25	25	25	25	Moderate to heavy
5--7	145	130	130	129	,, ,,
10	26	26	26	26	Heavy
12	37	None	...	...	No infection
14	26	,,	...	...	,,
16	1	,,	...	...	,,
20 - 22	37	,,	...	...	,,

TABLE III

Summary of results of inoculations made, from time to time, on Berberis lycium *Royle (plants raised from root-wood) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	3	3	3	3	Heavy
3	36	35	35	35	Moderate to heavy

TABLE III—*contd.*

1	2	3	4	5	6
5	14	14	14	14	Moderate to heavy
7	41	41	41	39	„ „
5—7	137	94	89	70	Light to moderate
8	2	2	2	2	Moderate
9	2	2	2	2	„
10	42	38	38	38	Moderate to heavy
12	39	None	...	...	No infection
14	21	„	...	...	„
18	5	„	...	...	„
20—25	54	„	...	...	„

TABLE IV

Summary of results of inoculations made, from time to time, on Berberis aristata *DC.* (*seedlings raised from seed the same season and less than six months old*) *with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
„ 2 = Total number of leaves inoculated
„ 3 = „ „ „ „ showing spermogonia
„ 4 = „ „ „ „ on which nectar was mixed
„ 5 = „ „ „ „ „ „ aecidia appeared
„ 6 = Nature of infection

1	2	3	4	5	6
1	10	8	8	5	Light
2	31	26	26	19	„
3	38	28	28	23	„
4	3	None	...	...	No infection
5	43	„	...	...	„
7	37	„	...	...	„
5—7	19	„	...	...	„
10	2	„	..	...	„

Table V

Summary of results of inoculations made, from time to time, on Berberis aristata *DC. (plants raised from seed and more than six months old) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	37	5	5	None	Only a few spermogonia
3	49	4	4	,,	,, ,, ,,
5	50	None	...	...	No infection
7	38	,,	...	...	,,
5—8	81	,,	...	...	,,
9	5	,,	...	...	,,
10	1	,,	...	...	,,

Table VI

Summary of results of inoculations made, from time to time, on Berberis aristata *DC. (plants raised from root-wood) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	16	None	...	...	No infection
3	56	,,	..	..	,,

TABLE VI—*contd.*

1	2	3	4	5	6
4	7	None	...	...	No infection
5	49	,,	...	...	,,
7	40	,,	...	...	,,
5—8	115	,,	...	...	,,
9	2	,,	...	...	,,
10	19	,,	...	...	,,
12	7	,,	...	...	,,
14	2	,,	..	..	,,

TABLE VII

Summary of results of inoculations made, from time to time, on Berberis coriaria *(seedlings raised from seed the same season and less than six months old) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
1	12	7	7	1	Light
2	19	14	14	7	,, *
3	34	19	19	10	,,
4	3	None	...	...	No infection
5	33	2	2	Neither	Only a few spermogonia
5—7	63	None	...	...	No infection
7	25	,,	...	...	,,
8	3	,,	...	...	,,

*In one experiment, heavy infection with marked hypertrophy took place.

Table VIII

Summary of results of inoculations made, from time to time, on Berberis coriaria *(plants raised from seed and more than six months old) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
1	6	1	1	None	Only a few spermogonia
3	37	1	1	,,	,, ,, ,,
4	4	None	...	..	No infection
5	35	,,	...	...	,,
7	25	,,	..	...	,,
5—7	60	,,	...	...	,,
10	5	,,	...	...	,,

Table IX

Summary of results of inoculations made, from time to time, on Berberis coriaria *(plants raised from root-wood) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	17	None	.	...	No infection
3	47	,,	...	...	,,

TABLE IX—*contd.*

1	2	3	4	5	6
4	4	None	...	...	No infection
5	38	,,	...	...	,,
7	23	,,	...	...	,,
8	4	,,	...	...	,,
5—8	77	,,	...	...	,,
10	17	,,	..	...	,,
12	6	,,	...	...	,,

TABLE X

Summary of results of inoculations made, from time to time, on Berberis petiolaris *(plants raised from root-wood) with germinating teleutospores of* P. graminis *tritici*

Column 1 = Age of leaves in days
,, 2 = Total number of leaves inoculated
,, 3 = ,, ,, ,, ,, showing spermogonia
,, 4 = ,, ,, ,, ,, on which nectar was mixed
,, 5 = ,, ,, ,, ,, ,, ,, aecidia appeared
,, 6 = Nature of infection

1	2	3	4	5	6
2	15	None	...	...	No infection
3	24	,,	...	...	,,
5	81	,,	...	...	,,
7	17	,,	...	...	,,
5—8	116	,,	...	...	,,
10	4	,,	...	...	,,

TABLE XI

Summary of results of inoculations made, from time to time, on Berberis umbellata? *(raised from seed obtained from Switzerland) with germinating teleutospores of* P. graminis tritici

Column 1 = Age of leaves in days
„ 2 = Total number of leaves inoculated
„ 3 = „ „ „ „ showing spermogonia
„ 4 = „ „ „ „ on which nectar was mixed
„ 5 = „ „ „ „ „ „ aecidia appeared
„ 6 = Nature of infection

1	2	3	4	5	6
2	3	None	...	...	No infection
3	17	„	...	...	„
5	7	„	...	...	„
7	3	„	...	...	„
5—7	14	„	...	...	„
14	2	„	...	...	„

The results shown in the above tables are summarized below. Information from literature regarding the reaction of each of the species to *P. graminis tritici*, the black rust of wheat, if available, as well as its distribution in the hills of India has also been given :

(i) *Berberis vulgaris* Linn. (foreign), as elsewhere, has been found to be heavily susceptible. It was infected in the seedling stage as well as up to the age of five years. Plants older than that were not available. In this connection, it is important to note that leaves older than 12 days could not be infected, although the plants were kept under protection. Cotter [1932] reported infection of several fresh leaves of this species up to the age of 12-15 and, in one case, even 16 days in U. S. A. Levine and Cotter [1932] have quoted this species to be heavily susceptible to *P. graminis tritici*. This species, wherever found, has been known to be most suscepitible to all the 'Specialized forms' of *P. graminis* Pers.

Plants of *B. vulgaris*, var. 1. *vulgaris* proper, of Hooker [1875] that were collected from Narkunda, Simla hills, during these studies, were identified by the Forest Botanist, Dehra Dun, as *B. petiolaris* Wall. (Syn. *B. pachyacantha* Koehne) as described by Parker [1924]. The Forest Botanist also informed the

writer, on the authority of Schneider [1905], that true *B. vulgaris* Linn. does not occur in India. Enquiries have also been made by the writer from the Superintendent, Sibpur Herbarium, Calcutta, as well as from the Director, Royal Botanic Garden, Kew, and the information kindly supplied by them shows clearly that the species in question is not a native of the Himalayas. In their monograph, Butler and Bisby [1931] reported the occurrence of aecidia of *P. graminis* on *B. vulgaris*. It appears, that the species they had in view was *B. vulgaris*. var. 1. *vulgaris* proper, according to Hooker [1875], which is the same as *B. petiolaris* Wall. (Syn. *B. pachyacantha* Koehne), as described by Parker [1924] or some other variety of *B. vulgaris*, as described by Hooker.

Further, Levine and Cotter [1932] have given a long list of synonymous species and varieties of *B. vulgaris* L., marked as extremely susceptible to *P. graminis* and it is important to note that none of the five varieties of this species, described in Hooker's flora [1875], is included in that list.

(ii). *B. lycium* Royle (indigenous), has been found to be moderately susceptible in the seedling stage as well as in the case of plants raised from root-wood. Only fresh leaves up to the age 10 days have produced aecidia, although the plants were kept under protection. According to Melander and Craigie [1927], this species is resistant to sporidia of *P. graminis tritici*.

Cotter [1932] recorded this species to be moderately susceptible but Levine and Cotter [1932] mentioned a " wide range of infection from light pycnial (spermogonial) to heavy aecial (aecidial) infection ".

There is no information in literature regarding the number of days up to which fresh leaves of this species have been found to be susceptible, by other workers.

According to Hooker [1875], this species is found at altitudes of 8,000-9,000 ft. in the Himalayas but Parker [1918] gives its distrubition as 3,000-7,000 ft. only.

During the course of these studies, this species has been found to be very common in the lower altitudes of Kumaon and Simla hills, including the neighbourhood of Simla proper. From Simla upwards, it is rather rare and does not occur beyond Mattiana, nearly 7,500 ft.

(iii). In the case of *B. aristata*, so far only fresh leaves of seedlings up to the age of 8 days have produced aecidia. Young plants, raised from seed, in the second season of their growth produced only spermogonia on leaves 8 days old and no infection took place in the case of leaves of plants raised from rootwood even at the age of 2-3 days.

According to Melander and Craigie [1927] and Cotter [1932], this species is susceptible to black stem-rust but information regarding its reaction to *P. graminis tritici*, the black rust of wheat, is doubtful, as recorded by Levine and Cotter [1932] in their Table II. In Table I, these authors have quoted the reaction of this species as " light infection ; pustules rather small at times though often quite large ".

Butler and Bisby [1931] mentioned *B. aristata* as one of the four species on which aecidia of *P. graminis* had been found. According to Hooker's flora of British India [1875], this species is as variable as *B. vulgaris* and it has three distinct varieties. It is quite likely, therefore, that the variety which Butler and Bisby had in view, was not the same on which inoculations have been made during these studies. Seed and root-wood used for raising plants of this species for inoculation experiments were collected from the neighbourhood of Simla. Collett [1921] described this species as *B. aristata*, DC. Keeping in view the description and distribution of the three varieties mentioned by Hooker, the plants used in these studies resemble var. 1. *aristata* and are very different from var. 2. *floribunda*, Syn. *B. coriaria* Royle or var. 3. *micrantha*. The distribution of this species, as given in Hooker [1875] is Temperate Himalayas, altitude 6,000-10,000 ft. but according to Collett [1921] it is found only at altitudes of 6,000-7,000 ft. During these studies, the species under reference has not been found to grow beyond Mattiana (7,500 ft.) on the way to Narkunda.

(iv). *B. coriaria* Royle, Syn. *B. aristata* var. 2. *floribunda*, according to Hooker's flora [1875], was also included in these studies because it is very common at higher altitudes of the Simla hills. Collett [1921] described this as a separate species.

Fresh leaves only up to age of 3 days, in the case of seedlings, have produced aecidia. In one experiment, spermogonia were formed on leaves 5 days old. Plants, raised from seed, in the second year of their growth, developed only spermogonia on leaves up to the age of 3 days and no infection took place on leaves of plants raised from root-wood.

There is no record of the occurrence of aecidia of *P. graminis* on this species in India. Levine and Cotter [1932] have quoted this species, while referring it to *B. aristata* Royle, as susceptible to black stem-rust. With regard to its reaction to *P. graminis tritici*, the black rust of wheat, there is no information in literature. According to Collett [1921], this species occurs at altitudes, 7,000-10,000 ft.

(v). *B. petiolaris* Wall. (Syn. *B. pachyacantha* Koehne), according to Parker [1924], *B. vulgaris*, var. 1. *vulgaris* proper according to Hooker [1875], was included in the list because of the reported occurrence of aecidia of *P. graminis* on *B. vulgaris* by Butler and Bisby [1931]. Collett [1921] described this species after Hooker as *B. vulgaris* Linn, but, as stated above, on the authority of Schneider [1905], true *B. vulgaris* Linn. does not occur in India.

Plants of *B. petiolaris* were raised from root-wood collected at Narkunda, where only a few bushes are found. No work could be done on the seedlings of this species for want of good seed. Year after year, no ripe berries could be found on the plants at Narkunda and seed obtained from Kashmir and other places did not germinate.

No infection took place on fresh leaves of plants raised from root-wood, up to the age of 10 days. Even spermogonia were not formed. No information is available in literature regarding its reaction to any of the 'Specialised Forms' of *P. graminis* Pers.

The distribution of this species, according to Collett [1921], is 8,000-12,000 ft. but *B. vulgaris*, var. 1. *vulgaris* proper is shown to occur at altitudes of 5,000-10,000 ft. by Hooker [1875].

(vi). In addition to the five species mentioned above, several inoculations were made on seedlings as well as older plants up to the age of three years in the case *B. umbellata*? (Swiss). No infection took place even on leaves of seedlings 2-8 days old. As stated in Part One, seed of this species was obtained from Switzerland

It is important to note that *B. umbellata* is one of the species reported to be susceptible by Cotter [1932] as well as Levine and Cotter [1932]. In India also, aecidia of *P. graminis* have been reported to occur on this species by Butler and Bisby [1931]. The plants raised from Swiss seed did not flower and it is difficult to say if the seed really belonged to this species. No conclusion can, therefore, be drawn from the experiments carried out so far, regarding the reaction of this species. All efforts to obtain seed from other sources outside India have been unsuccessful. Seedlings have recently been raised from seeds supplied by a firm at Darjeeling but the writer is unable to state if it was collected from a properly identified plant, unless a suitable herbarium specimen is available from the same source. As far as possible, reaction of this species will also be studied before long, provided reliable root-wood or seed are available.

This sepcies is not found in the Simla hills and according to Hooker [1875], it occurs in Temperate Himalayas, at altitudes of 9,000-11,000 ft. from Kumaon to Bhutan. Parker [1918] quotes its distribution as 4,000-9,000 ft. in the inner dry valleys of the Himalayas.

Seed of *B. tinctoria* Lesch., a variety of *B. aristata* according to Hooker [1875] as well as Fyson [1932] but a separate species according to Schneider [1905], has recently been obtained from the Nilgiris where it is very common and plants from root-wood have also been raised. In view of the fact that Schneider has divided the barberry plants in the Nilgiris into three distinct species, the writer is not sure of the identification of the material supplied. If possible, herbarium mounts will be obtained from the same plants from which seed was collected and sent out for identification. In the meanwhile, inoculations will be carried out on the seedlings as well as older plants, that are available. There is no record of the occurrence of aecidia of *P. graminis* Pers. on this species.. It is found only in the Nilgiri and Palni hills.

As recorded before, Arthur and Cummins [1933] identified aecidia of *P. graminis* Pers. on *B. pseudumbellata* collected by Stewart from Tangmarg (7,200 ft. in Kashmir). There is no reference to this species in Hooker's flora [1875]

nor has it been quoted by Collett [1921]. *B. pseudumbellata* Parker is described by Parker [1924]. It has not been possible to do any work on this species, for want of reliable seed or rootwood. As soon as suitable material is obtained, its reaction to *P. graminis tritici* will be studied. There is no information in literature regarding its reaction to that 'Specialized Form'.

10. General discussion

It has been stated before that in the plains of India there are no barberries and, as observed by the writer [Mehta, 1929 ; 1933], the uredospores of black rust, like those of yellow and brown, are killed year after year by the intense heat of summer, yet epidemics of this rust recur annually over the greater part of the plains. In the hills, however, there are several species of *Berberis* growing at different altitudes and the rôle of this host, therefore, is of unusal interest in this country.

During his study of cereal-rusts at Cambridge, the writer [Mehta, 1923] obtained satisfactory germination of the teleutospores of this rust, kept under natural conditions, without the adoption of any special methods. Study of the role of alternate hosts in India has, however, presented considerable difficulties, as one should expect, because of climatic conditions being widely different from those prevailing in temperate regions.

The question that naturally arises is, does the initial annual outbreak of black rust start from infected barberris, as happens over the greater parts of Europe and North America, or from uredospores that are able to oversummer in the hills? The various aspects of this question are fully discussed below.

(i) Germinability of teleutospores found in nature :—

It is well known that in cold countries teleutospores of black stem-rust are produced early in autumn, get buried under snow from time to time during winter and germinate profusely in spring, when fresh leaves appear on barberries.

In this country, on the other hand, teleutospores are produced at the end of winter or even spring, which happens to be of a very short duration. In the plains of Peninsular India and the United Provinces, they are usually formed during February-March and in the Punjab a month later. Unlike temperate climates, teleutospores in this country represent the Summer-Stage in the life-cycle of the parasite concerned.

All over the plains, therefore, teleutospores are exposed, from day to day, duing April-June to high temperatures, rising in some parts of the country to as much as 115°F. even in shade. After summer, these spores remain soaked during the monsoon (June-September) and then there is the winter which is rather mild and without any snow.

Johnson [1931] observed that teliospores formed at 50°-60°F. germinated more abundantly and consistently than those produced at 70°-75°F. and concluded that conditions of temperature during the period of formation have a considerable effect on their germinability.

It is not only the range of temperature at the time of formation ot teleutospores that matters but their viability is liable to be seriously affected also by subsequent exposure to high temperatures.

Stakman, Kirby and Thiel [1921] stated that teliospores formed in the Northern States of U. S. A., when kept in the South, produced no infection on barberries, which in the North are commonly infected. Lambert [1929] also observed that the viability of teliospores in States like Texas, Oklahoma, Southern Kansas, etc., that are formed during May-June is destroyed by exposure to hot summer in the months of July-September. Cotter [1932] remarked that if teliospores are not kept at a low temperature (about 0°C.) and dry, they lose their viability. Later, Stakman [1934] explained that the absence of infection on barberries in the far south of U. S. A. is due to the loss of viability of teliospores during the long hot summers. Novotelnova [1935] observed that teleutospores of *P. graminis avenae* are killed after exposure to 30°C. for 24 hours.

It is very unikely, therefore, that in the plains of India teleutospores, even though germinable at the time of formation, should retain any viability after exposure to summer. These conditions eliminate altogether the possibility of any infection of barberries in the hills, and there are none in the plains, by such teleutospores as may be blown by wind from the latter. Teleutospores collected from the crop at Agra in the month of March, 1934 and 1935, showed no germination, although they were kept in a refrigerator and also frozen for as long as two months. This shows that either the material was not germinable from the beginning, due to unfavourable temperature at the time of formation, or its viability was lost as a result of exposure to fairly high temperatures for a few days before collection. It may be mentioned that black rust appears at Agra usually by the third week of February and the teleutospores, therefore, could not be formed before March. Detailed information regarding those collections is given in Table XII and the temperature data of Agra in Appendix A.

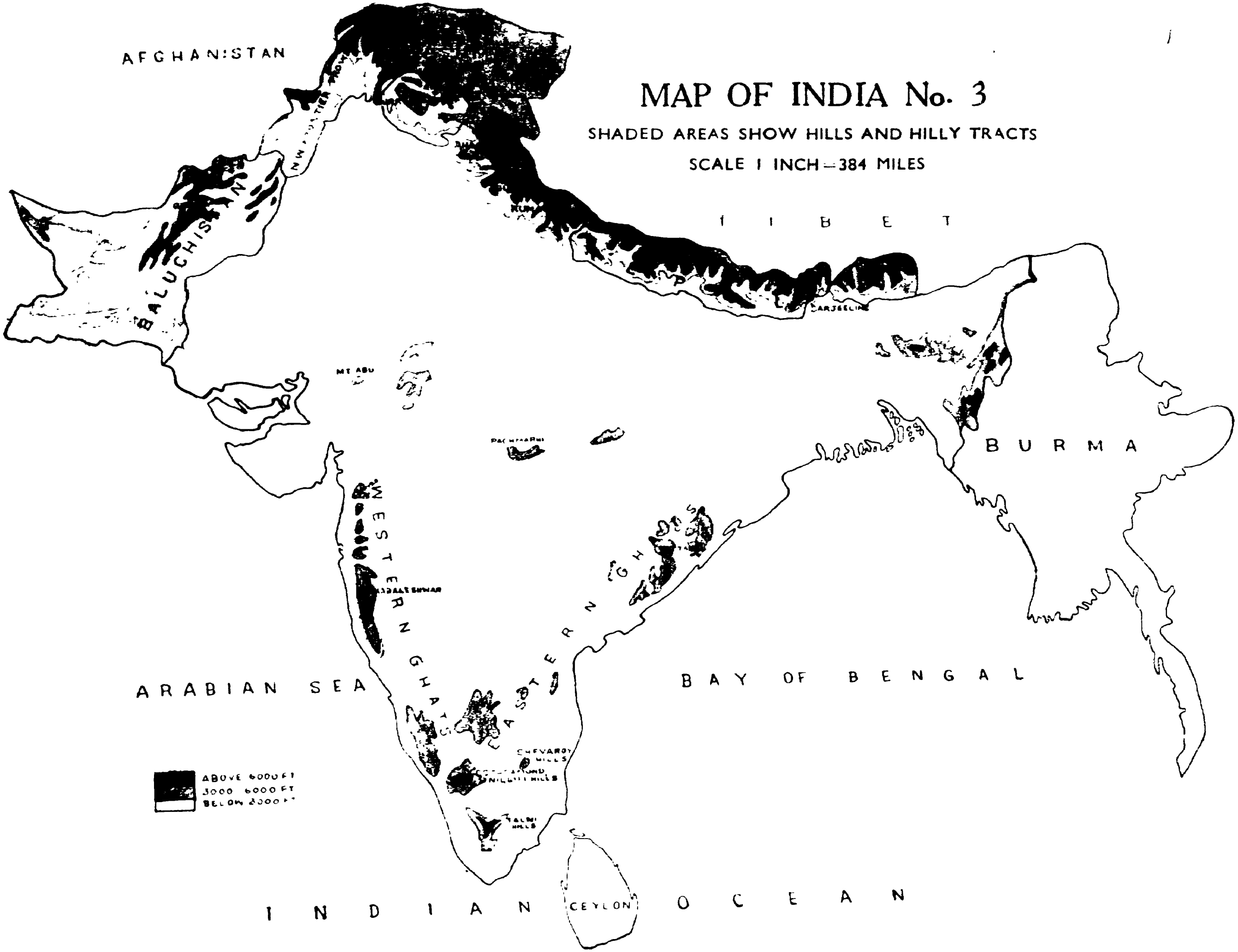
Reference may here be made to the germination tests carried out by Waterhouse [1929] in Australia, with the teleuto-material which he received from Pusa, India, collected on February 26th, 1922 and then again on March 12th, 1927. This author obtained germination from both the collections after their exposure to winter conditions for 5-6 months in Australia. It is difficult to know exactly the range of temperature under which the teleuto-materia on those two occasions was formed at Pusa because only the dates of collection are mentioned. Anyhow, it is certain that neither of those collections was exposed to high temperatures as they were removed from the rop before hot weather began. That explains why the collections retained their viability. The weekly average maximum and minimum, highest and lowest temperatures during February 1922 and March 1927, as obtained by request from the Director, Imperial (now Indian) Agricultural Research Institute, Pusa (now stationed at New Delhi), are given in Appendix B.

In the hills of India, although wheat and barley are sown about the same time

MAP OF INDIA No. 3

SHADED AREAS SHOW HILLS AND HILLY TRACTS

SCALE 1 INCH = 384 MILES



as in plains, i.e. October-November, they are harvested 2-3 months later (May-June) on account of slower growth. At altitudes of 3,000-5,000 ft., teleutospores are likely to be formed towards the end of winter or early in spring but they are liable to lose their viability because of exposure to high temperatures during April-June, the hottest part of the year. None of the collections obtained from lower altitudes germinated, although they were either kept in a refrigerator or exposed to natural conditions at Simla (7,000 ft. above sea level) and also frozen. Except at lower altitudes, teleutospores on the hill crops are produced during May-June, the hottest part of the year and it seems that normally the material collected from the sun is not germinable from the beginning, even at a place like Simla (nearly 7,000 ft. above sea level), where the shade temperature frequently exceeds 80°-85°F. during that period. Relevant information regarding collections of teleutospores from different altitudes in the Simla hills, their storage, further treatment and germination is given in Tables XIII-XV and of collections from the Nilgiris in Table XVI.

For convenience of reference, hills and hilly tracts are shown in Map No. 3.

TABLE XII

Detailed information regarding collections of Teleutospores of black rust from the wheat crop at Agra, their storage, further treatment and germination. All germination tests were made at 50°-65°F

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From crop 1933-34 ; collected on 31st March, 1934 ; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days, followed by 3 dryings and wettings, each for 2 days	None	Germination was tested in May, 1934
2	From crop 1934-35 ; collected on 24th March, 1935 ; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during October to December, 1935

TABLE XIII

Detailed information regarding the various collections of Teleutospores of black rust from the wheat crop or stubble at the lower altitudes of Simla hills (3,600-4,900 ft. above sea level), their storage, further treatment and germination. All germination tests were made at 50°-65°F.

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From crop 1934-35 at Kandaghat (4,700 ft. above sea level) ; collected on 27th May, 1935 from shade ; exposed to natural conditions at Simla	(*a*) Frozen artificially for 3 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during August, 1935 to March, 1936
		(*b*) No artificial freezing was done	None	Germination was tested in March, 1936

TABLE XIII—*contd.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
2	From crop 1934-35 at Kandaghat; collected on 27th May, 1935 from sun; exposed to natural conditions at Simla	(*a*) Frozen artificially for 3 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during August, 1935 to March, 1936
		(*b*) No artificial freezing was done	None	Germination was tested in March, 1936
3	From crop 1934-35 at Kandaghat; collected on 27th May, 1935 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during October to December, 1935
4	From crop 1934-35 at Kandaghat; collected on 27th May, 1935 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during October to December, 1935
5	From crop 1934-35 at Solan (4,900 ft. above sea level); collected on 27th May, 1935 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during October to December, 1935
6	From crop 1934-35 at Dharampore (4,800 ft. above sea level); collected on 26th May, 1935 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during October to December, 1935
7	From stubble of crop 1935-36 at Kandaghat; collected on 25th June, 1936 from shade; kept exposed to natural conditions at Simla	Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
8	From stubble of crop 1935-36 at Kandaghat; collected on 25th June, 1936 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
9	From stubble of crop 1935-36 at Kandaghat; collected on 25th June, 1936 from sun; kept in a refrigerator (40°-50°F.) at Simla	Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
10	From stubble of crop 1935-36 at Solan; collected on 3rd June, 1936 from shade; kept exposed to natural conditions at Simla	(*a*) Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
		(*b*) No artificial freezing was done	None	Germination was tested in the latter half of February, 1937
11	From stubble of crop 1935-36 at Solan; collected on 3rd June, 1936 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
12	From crop 1935-36 at Solan; collected on 3rd June, 1936 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937

TABLE XIII—*concld.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
13	From stubble of crop 1935-36 at Dharampore; collected on 24th June, 1936 from shade; kept exposed to natural conditions at Simla	(*a*) Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
		(*b*) No artificial freezing was done	None	Germination was tested in the latter half of February, 1937
14	From stubble of crop 1935-36 at Dharampore; collected on 24th June, 1936 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 20 days to 2 months, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during December, 1936 to February, 1937
15	From crop 1936-37 at Koti (3,600 ft. above sea level); collected on 25th March, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 10 days to 1 month, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during January-February, 1938

TABLE XIV

Detailed information regarding the various collections of Teleutospores of black rust from the wheat crop, stubble or straw at Simla (altitude nearly 7,000 ft.), their storage further treatment and germination. All germination tests were made at 50°-65°F.

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From crop 1931-32; collected in June, 1932 from shade; kept exposed at Narkunda from September, 1932 to May, 1933; stored in a room at Simla till August, 1933	Frozen artificially for 3 days; 4 days' wetting followed by drying and wetting, each for 3 days	0-10 per cent	Narkunda is nearly 2,000 ft. higher than Simla. Germination was tested on different dates in August, 1933
2	From crop 1932-33; collected in May, 1933 from sun; kept in a room at Simla till December, 1933; placed out in snow in January, 1934	Frozen artificially for 11 days followed by 2 dryings and wettings, each for 2 days	None	Germination was tested in February, 1934
3	From crop 1932-33; collected on 3rd June, 1933 from shade; kept in a room at Simla.*	Frozen artificially for 4-7 days followed by 8 days' wetting	5-60 per cent	Germination was tested several times in August, 1933
4	From crop 1932-33; collected on 3rd June, 1933 from shade; kept in a refrigerator (at 40°-50°F.) at Simla*	Frozen artificially for 4-7 days, followed by 3 days' wetting	40-60 per cent	Germination was tested several times in September, 1933
5	From stubble of crop 1932-33; collected in November, 1933 from pure line seed plots, where the teleuto-stage was observed in June preceding	Frozen artificially for 11 days followed by 2 dryings and wettings, each for 2 days	None	Germination was tested in November, 1933

* Same collection.

TABLE XIV—*contd.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
6	From straw of crop harvested in June, 1933; lying exposed to natural conditions near a threshing ground till March following	Frozen artificially for 11 days followed by 2 dryings and wettings, each for 2 days	None	Germination was tested March, 1934
7	From crop 1933-34; collected on 30th May, 1934 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 8 days followed by 2 dryings and wettings, each for 2 days	Nearly 10 per cent	Germination was tested November, 1934
8	From crop 1933-34; collected on 30th May, 1934 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 8 days followed by 2 dryings and wettings, each for 2 days	None	Germination was tested in November, 1934
9	From crop 1934-35; collected on 30th May, 1935 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 3 days to 3 months; 2 dryings and wettings, each for 2 days	None	Germination was tested several times between August, 1935 and January, 1936
10	From crop 1934-35; collected on 30th May, 1935 from shade; exposed to natural conditions	(*a*) No artificial freezing was done (*b*) Frozen artificially for 7-20 days	None None	Germination was tested several times in February-March, 1936
11	From crop 1934-35; collected on 30th May, 1935 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially from 3 days to 3 months, 2 dryings and wettings, each for 2 days	None	Germination was tested several times in February-March, 1936
12	From crop 1935-36; collected on 23rd May, 1936 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 15 days to 2 months, followed by 2 dryings and wettings for 2 days each	None	Germination was tested several times between November, 1936 and February, 1937
13	From crop 1936-37; collected on 15th May, 1937 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days to 2 months, followed by 2 dryings and wettings for 2 days each	None	Germination was tested several times between November, 1937 and February, 1938

TABLE XV

Detailed information regarding the various collections of Teleutospores of black rust from wheat stubble at higher altitudes in the Simla hills (7,500-9,200 ft. above sea level), their storage, further treatment and germination. All germination tests were made at 50°-65°F.

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From stubble of crop 1936-37 at Theog (7,500 ft. above sea level); collected on 10th July, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	(*a*) Frozen artificially for 20 days, followed by 2 dryings and wettings, each for 2 days (*b*) Frozen artificially for 1 month, followed by 2 dryings and wettings, each for 2 days	0 per cent 2 per cent	Germination was tested several times during January-February, 1938

TABLE XV—*contd.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
2	From stubble of crop 1932-33 at Narkunda (9,200 ft. above sea level); collected on 10th October, 1933 from sun; kept in a refrigerator (at 40°-50°F.) at Simla.	Frozen artificially for 10 days followed by 2 dryings and wettings, each for 2 days	None	Germination was tested in December, 1933
3	From stubble of crop 1932-33 at Narkunda (9,200 ft. above sea level); collected on 10th October, 1933 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 8 days followed by 2 dryings and wettings, each for 2 days	40 per cent	Germination was tested in January, 1934
4	From stubble of crop 1932-33 at Narkunda (9,200 ft. above sea level); collected on 10th October, 1933 from sun; kept exposed to natural conditions at Narkunda till May, 1934	(*a*) No artificial freezing was done	5 per cent	Germination was tested in July, 1934
		(*b*) Frozen artificially for 7 days	10 per cent	
5	From stubble of crop 1932-33 at Narkunda (9,200 ft. above sea level); collected on 10th October, 1933 from shade; kept exposed to natural conditions at Narkunda till May, 1934	(*a*) No artificial freezing was done	40 per cent	Germination was tested in July, 1934
		(*b*) Frozen artificially for 7 days	40 per cent	

TABLE XVI

Detailed information regarding the various collections of Teleutospores of black rust from the wheat crop or stubble at different places in the Nilgiri hills (altitudes of 6,400-7,000 ft.) their storage, further treatment, and germination. All germination tests were made at 50°-65°F.

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From crop sown in June, 1936 at Keakhutty (6,800 ft. above sea level); collected on 4th October, 1936; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 20 days for 2 months, followed by 2 dryings and wettings, each to 2 days	None	Germination was tested several times during January and February, 1937
2	From crop sown in May-June, 1937 at Hoosatti (6,700 ft. above sea level); collected on 16th October, 1937 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 12 days to 1 month, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times in January, 1938
3	From stubble of crop harvested in October, 1937 at Hoosatti (6,700 ft. above sea level); collected on 20th December, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 to 20 days, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times during January and February, 1938

TABLE XVI *contd.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
4	From crop sown in June, 1937 at Kalakorai (6,900 ft. above sea level); collected on 15th October, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 10 days to 1 month, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times in January, 1938
5	From stubble of crop, harvested in October, 1937 at Melkavatti (7,000 ft. above sea level); collected on 20th December, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 to 20 days, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times in January, 1938
6	From stubble of crop Pusa 4, sown on 15th July, 1937 and harvested before 19th December, 1937 at Nanjanad Farm (7,000 ft. above sea level); collected on 19th December, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 to 20 days, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times in January, 1938
7	From stubble of crop harvested in last week of November 1937 at Kilkavatti (6,400 ft. above sea level); collected on 20th December, 1937 from sun; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 to 20 days, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested several times in January, 1938

It is clear from these tables that normally there is very little viable teleuto-material from the crop up to altitudes of nearly 7,000 ft. above sea level. At Simla, for instance, out of 13 collections made during six years from the wheat crop, it seems only 3 were viable at the time of their formation and these were collected from the shade. After collection, these samples were kept either in a room or a refrigerator. None of the collections from material exposed to natural conditions germinated. A record of weekly average maximum, minimum and highest temperatures at Simla during May-June for those six years is given in Appendix C.

As far as the writer can see, it is the scarcity of germinable teleutospores even in the hills of this country that is responsible, more than any other factor, for the extreme rarity of the aecidial stage, as experienced during these studies, even on *B. lycium* which, as stated before, is moderately susceptible to black rust but occurs only at the lower altitudes, i.e., 3,000-7,000 ft. It is clear that infection of *Berberis* at a place like Bhimtal (4,500 ft. above sea level), referred to by the writer in an earlier article [Mehta, 2929], is very unlikely. The aecidial material found at the locality has been identified as *Aecidium montanum* Butl.

While that seems to be true of the greater part of the area under wheat and barley cultivation in the hills, one has to reckon with the possibility of the formation of germinable teleutospores at the higher altitudes because of cooler weather during May-July, as would be clear from germination tests given in Table XV. Besides, germinable teleutospores are likely to be formed on self-sown plants,

tillers,* etc., which bear the oversummering uredostage, early in winter, when the range of temperature for their formation is most favourable. Such material was also produced by artificial inoculations in miniature plots at Simla and an account of their germination is given in Table XVII. A record of monthly average maximum, minimum, highest and lowest temperatures of Simla during October-December for a period of six years is supplied in Appendix D.

While summing up, it may be safely observed that normally there is scarcity of germinable teleuto-material available from the crops, over the greater part of the area under wheat and barley in the hills of India, i.e. up to altitudes of nearly 7,000 ft. above sea level. However, teleutospores formed on crops at altitudes still higher, specially in shaded parts of fields and those produced during winter on self-sown plants and tillers, should be a source of infection to barberries in the following spring.

TABLE XVII

Detailed information regarding the various collections of Teleutospores of black rust from miniature plots, self-sown plants and tillers of wheat at Simla, their storage, further treatment and germination. All germination tests were made at 50°-65°F.

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From miniature plot; formed in winter of 1932-33; collected on 13th April, 1933	No artificial freezing was done and put for germination directly	20 per cent	Germination was tested in April, 1933
2	From miniature plot; formed in winter of 1932-33; collected on 16th May,† 1933; kept in a refrigerator (at 40°-50°F.) at Simla	No artificial freezing was done	60 per cent	Germination was tested several times during September, 1933 to January, 1934
3	From miniature plot; formed in winter of 1932-33; collected on 16th May,† 1933; kept in a room at Simla	No artificial freezing was done	5 per cent	Germination was tested in November, 1933
4	From miniature plot; formed in winter of 1933-34; collected on 30th January, 1934; kept in a refrigerator (at 40°-50°F.) at Simla	No artificial freezing was done	40 per cent	Germination was tested in November, 1934
5	From miniature plot; formed in winter 1933-34; collected on 30th January, 1934; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 4 to 9 days	90 per cent	Germination was tested several times during February to December, 1934
6	From miniature plot; formed in winter of 1934-35; collected on 5th December, 1934	Frozen artificially for 7 days, directly after collection	20 per cent	Germination was tested in the middle of December, 1934
7	From miniature plot; formed in winter of 1934-35; collected on 12th January, 1935	Frozen artificially for 10 days, directly after collection	40 per cent	Germination was tested during January to February, 1935
8	From miniature plot; formed in winter of 1934-35; collected on 1st February, 1935	Frozen artificially for 8 days, directly after collection	50 per cent	Germination was tested in February, 1935

* This term, wherever used refers to ratoon tillers from harvested plants.

† The weekly average maximum and highest temperatures at Simla during the first fortnight of May, 1933 were 60·1° and 68°F. respectively.

TABLE XVII—*contd.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
9	From miniature plot; formed in winter of 1934-35; collected on 5th February, 1935	Frozen artificially for 7 days, directly after collection	60 per cent	Germination was tested in February, 1935
10	From miniature plot; formed in winter of 1934-35; collected on 16th February, 1935	Frozen artificially for 8 days, directly after collection	90 per cent	Germination was tested several times during February to March, 1935
11	From miniature plot; formed in winter of 1934-35; collected on 16th February, 1935; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 8 weeks	90 per cent	Germination was tested in March, 1935
12	From miniature plot; formed in winter of 1934-35; collected on 15th March, 1935	Frozen artificially for 10 days, directly after collection	90 percent	Germination was tested in March, 1935
13	From miniature plot; formed in winter of 1934-35; collected on 15th March, 1935; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 5 to 6 days	100 per cent	Germination was tested several times during August, 1935 to February, 1936
14	From miniature plot; formed in winter of 1934-35; collected on 21st March, 1935	Frozen artificially for 9 days, directly after collection	100 per cent	Germination was tested in April, 1935
15	From miniature plot; formed in winter of 1934-35; collected on 1st April, 1935	Frozen artificially for 10 days, directly after collection	90 per cent	Germination was tested in April, 1935
16	From miniature plot; formed in winter of 1935-36; collected on 11th January, 1936; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 8 days	90 per cent	Germination was tested several times during February, 1936 to February, 1937
17	From miniature plot; formed in winter of 1936-37; collected on 15th February, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days	90 per cent	Germination was tested several times during February to April, 1937
18	From miniature plot; formed in winter of 1936-37; collected on 15th February, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	No artificial freezing was done	50-90 per cent	Germination was tested several times during April and May, 1937
19	From miniature plot; formed in winter of 1937-38; collected on 17th December, 1937	Frozen artificially for 10 days directly after collection	90 per cent	Germination was tested several times during December, 1937 to February, 1938
20	From miniature plot; formed in winter of 1937-38; collected on 7th February, 1938	Frozen artificially for 7 days, directly after collection	90 per cent	Germination was tested several times during February and March, 1938
21	From miniature plot; formed in winter of 1937-38; collected on 7th February, 1938	No artificial freezing was done; put for germination directly after collection	50 per cent	Germination was tested several times during February and March, 1938
22	From self-sown plants exposed to natural snow; collected from Simla on 30th January, 1934; kept in a refrigerator (at 40°-50°F.) at Simla	No artificial freezing was done. Germination was observed after prolonged and continuous wetting for 10 days	40 per cent	Germination was tested in February, 1934

TABLE XVII—*concld.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
23	From self-sown plants exposed to natural snow; collected from Simla on 30th January, 1934; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days	80 per cent	Germination was tested in April, 1934
24	From tillers of crop 1933-34 at Simla; collected on 21st September, 1934 from shade	Frozen artificially for 6 days directly after collection	10 per cent	Germination was tested in September, 1934
25	From tillers of crop 1933-34 at Simla; collected on 21st September, 1934 from shade; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days followed by wetting for 4 days	25-50 per cent	Germination was tested several times during October and November, 1934

In this table, only germination as observed before prolonged storage, has been recorded. Considerable variations in the germinability of these collections were noticed from time to time, when tested for inoculations on the alternate host.

(ii) Influence of weather conditions on the germination of teleutospores and subsequent infection of barberries :—

Normally, at a place like Simla (nearly 7,000 ft.) the range of temperature is quite favourable for the germination of teleutospores during the latter half of March and early in April. Lambert [1929] observed that teleutospores germinated well at 12°-18°C. but most consistently at the latter. Cotter [1932] stated that temperatures ranging from 12°-21°C. are the most favourable for the germination of teliospores, infection of barberries and the production of aecia.

It seems that general dryness of the weather during March-May makes the germination of teleutospores in the hills of India more capricious than elsewhere. There is no reason otherwise, why in the presence of plenty of viable teleuto-material in the miniature plots at Simla, from year to year, no infection should have taken place on any of the bushes of *Berberis lycium*, a moderately susceptible species, growing in the compound of the laboratory. At Simla, fresh leaves start appearing on barberries in the month of March. Rousakoff [1926] observed that rainfall, fogs and heavy dews are important factors in the spring germination of teleutospores. According to Lambert [1929], abundant germination of teliospores and the formation of sporidia takes place only in a saturated atmosphere. Only a few sporidia were produced in his experiments at 95 per cent relative humidity and none in less humid atmosphere. This author concluded that in nature germination of teliospores and the liberation of sporidia must take place during rains. Recently, Novotelnova [1935] also stated that no germination of teleutospores takes place below 100 per cent humidity.

It is well-known that sporidia of *P. graminis* are able to infect only fresh leaves of barberries up to the age of two weeks or so. If at the time of germination of teleutospores, new leaves are not available or if weather conditions for their germination are not favourable when barberries put forth new leaves, no infection may take place. Rousakoff [1926] observed that the germination of

teleutospores stands in no relation to the time of the development of leaves on barberries but depends on meteorological conditions. This explains, as stated by that author, the different degrees of intensity to which the aecidial stage develops in different years. Peltier [1929] stated that, for the successful infection of barberries, viable teleutospores must be present near the bushes together with environmental conditions favouring their germination and subsequent production of sporidia. Barberry leaves at the right age and conditions favourable for infection by sporidia must be at hand. This author concluded that one or more of these essential factors are absent each spring in many parts of Nebraska, U. S. A. Cotter [1932] has made the following observations on the infection of barberries in nature :—

" Infection may not occur even though the teliospores have germinated and the sporidia have lodged upon the barberry leaf. In nature, the conditions at the time the barberry leaves are unfolding are extremely variable. Rains may be intermittent, so that the film of moisture necessary to the life of the sporidium may disappear before the germ tubes can penetrate the leaf ; the temperature may drop so low that growth of the germ tubes is very slow, while the cuticle and epidermis of the leaf is thickening to such an extent that the germ tube can not penetrate it ; or the teliospores may germinate before the barberry leaves appear."

In Australia, Waterhouse [1934] recorded the only case of natural infection of barberry and observed that the climatic conditions at Yetholme, situated at an altitude of 4,000 ft., approximate to English conditions and are not extensively replicated in New South Wales.

The amount of rainfall and atmospheric humidity at Simla during March-May for a period of six years is given in Appendix E. It would be clear from those data that, normally atmospheric humidity at Simla is not very favourable for the germination of teleutospores and the subsequent infection of barberries during that time of the year. At the higher altitudes also, weather during spring is rather dry.

From the point of view of humidity, germination of teleutospores, wherever viable material is available, is more likely in the hills of India during the monsoon (June-August) if temperature permits but any infection of barberries, so late as that, would be of little consequence to the wheat and barley crops, as they are harvested mostly in May-June. In this connection, it may be repeated that Barclay [1887] reported the occurrence of aecidia of *P. graminis* in the Simla hills during August and, as recorded by Arthur and Cummins [1938], Stewart collected such aecidia from Tangmarg (7,200 ft above sea level in Kashmir) in July. As stated before, there is no information regarding the ' Specialized Form ' of black rust to which the aecidia observed by these authors belonged. That aecidia formed as late as July, even though connected with the black rust of wheat, could not be responsible for the initial attack on cereals at Tangmarg (Kashmir), would be clear from the fact that, during the course of these studies, the wheat crop near Pahalgam and Gulmarg, not far from Tangmarg, showed as much as 50-60

per cent infection with black rust, in the first week of that month. At Gulmarg and in the neighbourhood, the wheat and barley crops are harvested during July.

Regarding the occurrence of aecidia of *P. graminis* in the Nilgiri and Palni hills, there is no information in literature. No such aecidia were found during these studies either. Teleutospores formed on the second crop (sown in August-September) in these hills should be germinable to start with but soon after the harvest (February) the weather gets fairly warm. Besides, there is no snowfall in these hills, situated as they are, in extreme south of the country.

It may, therefore, be safely concluded that, with the exception of certain areas where conditions of weather may be more favourable than those described above, infection of barberries prior to the outbreak of black rust on cereals is very doubtful. This conclusion is based on an intensive study of the incidence of black rust in the Simla hills for a period of nearly ten years. Frequent observations were also made in Kumaon hills during 1930-33.

(iii) Source of annual recurrence of black rust in the plains of India :—

It has been stated before that wheat and barley crops are sown in plains as well as the hills, in general, during October-November. Year after year, black rust has been observed to appear at several places in the plains of India (Northern as well as Peninsular) in December-January, i.e. nearly 3-4 months before spring (March-April), which is the earliest period during which infection of barberries could take place in the hills. As a matter of fact, wheat and barley crops in the plains, excepting those of the Punjab, are actually harvested before that period.

Unlike the greater parts of Europe and North America, there is no case on record, with necessary data, of an outbreak of black rust on cereals in India in plains or even the hills, which could be connected with infected bushes of *Berberis*.

After ten years' study of the factors concerned in the annual recurrence of rusts in India, the writer [Mehta, 1933] observed that, as far as the plains are concerned, species of *Berberis*, the alternate host of black rust of cereals, seem to play little part in the yearly origin of that rust. Further, that this rust, in all probability, is disseminated to the plains from comparatively low altitudes, where, on account of a milder winter, its uredospores occurring at the time of sowing, cause outbreaks on the new crop rather early in the season. Oversummering of this rust, from year to year, in the uredostage like that of yellow and brown rusts of wheat, in the hills of India, has been repeatedly recorded by the writer. This rust has been found to oversummer at several places on self-sown plants even at altitudes of nearly 3,000-4000 ft. on the banks of a river during the hottest part of the year in the Kumaon hills [Mehta, 1933]. In the same article, reference has been made to the existence of several foci of infection in the hills of India, in north as well as the south.

Since then, the early crop (sown in August-September) at altitudes of 4,000-5,000 ft. in Central Nepal has been found to be infected with black rust during December. In one case, 20-40 per cent crop infection in different fields was noticed as early as the first week of that month. It is interesting to note that, as far as the United Provinces are concerned, this rust has been observed to break out earliest at the foot-hills and plains along the Nepal border, during the last eight years.

In the Nilgiris, this rust is found in the uredostage all the year round, i.e. on the crops (there are two in the course of the year) or on self-sown plants, tillers, etc. It may also be mentioned that, year after year, black rust is found on wheat and barley crops in the Nilgiris at 6,000-7,000 ft. in abundance by August-September on the first crop (sown in April-June).

Recent studies of the incidence of rusts in Peninsular India have sown the possibility of infection of 'out of season' wheat at the foot-hills as early as September-October. For instance, wheat sown, at the request of the writer, at Mandya in August 1935, showed nearly 5 per cent crop infection on October 16th following and at Coimbatore this rust broke out still earlier, i.e. September 10th, on wheat sown in June-July, 1937. Mandya and Coimbatore are situated at the foot of the Nilgiris on the north and south respectively. It may be mentioned that even by the circuitous hill road Mandya and Coimbatore are only 128 and 50 miles respectively from Ootacamund (Nilgiris).

Early dissemination of this rust from altitudes of nearly 6,000 ft. and above in the northern hills seems to be very unlikely because it does not break out on the crop at such places before March, although it is able to oversummer as well as overwinter there in the uredostage. On account of severe cold and occasional snow, it is improbable that this rust should spread rapidly from plant to plant during winter at such places. The duration of the incubation period in the case of inoculated seedlings kept in the open at Simla during December-January was found to be as long as 26 days, in one experiment. Whereas, oversummering of black rust in the uredostage at comparatively low altitudes (nearly 4,000-5,000 ft.) is an established fact, there is no evidence of the infection of barberries at such places, prior to the outbreak of this rust on the cereals. In fact, infection of barberries at such altitudes is very doubtful as has been fully discussed before.

Even if one presumed that teleutospores formed 'out of season' might cause infection at low altitudes, such teleutospores are likely to be formed only in early winter, i.e. November-December. Keeping in view the fact that weather during these two months is very dry and there is no snow at such altitudes, it is almost impossible for the teleutospores to germinate soon after their formation and infect barberries. The minimum period of dormancy even under the most favourable artificial conditions (freezing and alternate drying and wetting) has been found to be 20 days, by Johnson [1931]. In his experiments, frequent germination of teleutospores was obtained only 30-40 days after their formation and subsequent to the treatment, referred to above. Further, it would be

difficult to trace any outbreak of black rust in the plains during December-January from barberries directly or indirectly unless the latter are found to be infected latest by the middle of November, which seems impossible, as discussed above.

As far as the writer can see, outbreaks of black rust on wheat and barley crops in the plains are caused by the inoculum (uredospores) blown down from such places in the hills, where there is an early crop and consequently, an earlier appearance of the rust in question. Reference has already been made to two such foci, one in Nepal and the other in the Nilgiris. In short, there is no evidence, experimental or even circumstantial, on the basis of which one could connect outbreaks of black rust in the plains with previous infection on barberries in the hills of India. Further details regarding oversummering of the uredostage of this rust, in relation to its annual recurrence in hills as well as the plains are given in Section III.

(iv) Sources of annual recurrence of black rust in the hills :—

The fact that this rust breaks out, on account of the presence of oversummering uredospores, rather early in the season at lower altitudes in the hills has already been discussed in detail. No evidence could be obtained of an attack of black rust on cereals, starting from rusted barberries even at altitudes of 6,000-9,200 ft. in the Simla hills, during these studies and there is no case on record in literature either, to that effect. As a matter of fact, typical aecidia of *P. graminis* have not been found during these studies. On the other hand, there is conclusive evidence of the oversummering as well as overwintering of this rust in the uredo-stage at various altitudes in the hills of India. However, infection of barberries is likely in restricted areas, where weather conditions at the time of teleuto-formation, during the period of their dormancy, germination as well as throughout the incubation period, may be more congenial than have been described above. At the same time, it is obvious that infection of cereals therefrom is not at all of frequent occurrence, otherwise the number of physiologic races of this rust, at any rate in the hills, should have been very large.

This aspect of the question is discussed below.

(v) Infection of *Berberis* and the production of new races by hybridization on that host :—

Production of new physiologic races by hybridization on *Berberis* is a phenomenon too well-known to discuss in detail. It is enough to refer here to the work of Craigie [1927], Waterhouse [1929], Stakman, Levine and Cotter [1930], Newton and Johnson [1932], Stakman, Hines, Cotter and Levine [1932], Stakman, Levine, Cotter and Hines [1934] and Waterhouse [1934].

It has been stated in Part One that inoculations with single sporidia were outside the scope of this study. However, in almost all experiments on *Berberis*, nectar from different spermogonia was mixed at random and in one case two new races, not included in the latest key issued by Stakman and his co-workers were

found. Analysis of eleven samples of uredo-material produced on wheat by inoculations with aecidiospores from different species of *Berberis*, artificially infected, yielded only races 15, 40, 42 and 75, all of which had been found before. As recorded in Section I, only six races of this rust have been found in India so far. They are 15, 21, 24, 40, 42 and 75. The total number of collections analysed up to the end of March, 1938, was 586, out of which 157 were obtained from hills and hilly tracts.

Two out of the six races referred to above, i.e. 21 and 24 are very rare and the former has been found only once. In the opinion of the writer, the occurrence of such a small number of races is another proof, and perhaps the strongest of all, of the fact that infection of barberries in this country is by no means common. Otherwise, it is difficult to explain why, in the presence of millions of barberries in the hills, production of new races by hybridization on them, a phenomenon of such wide occurrence in other parts of the world, should have been in abeyance in this country.

(vi) Eradication of barberries :—

No discussion on the rôle of barberries would be complete without a reference to the need of their eradication which should be imperative in such countries, where initial outbreaks originate from them and also where the physiologic-race flora is rich. As stated before, in this country there is no case on record, with necessary data, of the infection of barberries prior to the outbreak of black rust on cereals. Even at Narkunda (9,200 ft. above sea level) or on its way from Simla, no evidence of this phenomenon could be obtained during the last ten years, although comparatively, the altitude of this part and weather conditions on the whole, are more favourable than in the rest of the area under intensive study.

The question that naturally arises is, should the barberries in India be destroyed, following the example of some of the European countries and that of U. S. A., where large sums of money have already been spent over this project because of its pressing need?

The different aspects of this question may be briefly answered as follows :—

Eradication of barberries will have little effect on outbreaks of black rust in the plains because of its appearance 3-4 months prior to the likely period of infection of the alternate host. Such eradication, even if carried out, will have no effect on the other two rusts, brown and yellow, that are equally destructive in this country and are found in plenty in the hills.

Judging from the small number of physiologic races found so far, it appears that, as in Australia, the formation of new races as a result of infection on barberries in this country occurs very rarely, if at all. At any rate, it is obvious that new races even if formed from time to time, do not spread to the cereals, otherwise one fails to understand why physiologic races found even in the hills should be so few.

Besides, the occurrence of race 15, which is found all over the country, has considerably eliminated the likelihood of a serious complication arising in work on the breeding of resistant varieties, due to the formation of a new race or races. Race 15 is the most virulent, in so far as eleven out of twelve differential hosts belonging to different species and varieties of *Triticum* are heavily susceptible to it. The twelfth differential is infected by race 42, which is also very common in this country.

The uredostage of black rust is sure to be killed from year to year, during winter at the higher altitudes, as happens over the greater parts of Europe and North America. This rust is unable to overwinter at Narkunda (9,200 ft. above sea level). It is improbable, therefore, that new races that may be formed on barberries at such altitudes, where their infection is more likely, should be able to propagate from season to season in the uredostage and there is very little wheat above 9,000 ft.

For the reasons given above, the writer feels convinced that the cost of eradication of barberries, and it would be millions of rupees, would never be commensurate, at any rate in this country, with the results that are likely to be obtained. This project would be inadvisable also because epidemics of all the three rusts will still recur unabated both in hills as well as the plains of India.

(vii) Conclusion :—

In conclusion, it may safely be stated that the most obvious source of infection of wheat and barley with black rust, from year to year, is the uredostage commonly found to be oversummering in the hills and not the post-epidemic infection of *Berberis*, if at all, in restricted areas at the higher altitudes.

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PART THREE

Rôle of *Thalictrum*

12. Review of literature

The earliest record of the connection between *P. triticina* Eriks., the brown rust of wheat, and *Thalictrum*, as an alternate host of that rust, was made by Jackson and Mains [1921]. These authors made inoculation experiments in U. S. A. on several genera belonging to the family Ranunculaceae and a few others with germinating teleutospores of *P. triticina* Eriks. and found only some species of *Thalictrum* to be susceptible to it. *T. flavum*, *T. Delavayi* and two unnamed species developed aecidia, whereas, only spermogonia, with occasional formation of aecidia took place on some other species. *T. minus* showed variable reaction, either no infection or only spermogonia and occasionally a weak development of aecidia.

Eremeyeva [1924] did some experimental work in U. S. S. R. on three species of *Thalictrum* and recorded the formation of spermogonia on *T. minus* only. Shitikova-Roussakova [1927, 1931] reported the occurrence of aecidia on *Thalictrum* in the Amur region, Leningrad area, etc. of U. S. S. R. but there is no experimental proof of their connection with the local outbreaks of brown rust on wheat. Waterhouse [1932] was able to infect *T. flavum* with sporidia of Australian races 1 and 2 of *P. triticina*.

Reference may here be made to the discovery of *Isopyrum fumarioides*, another aecidial host, as a result of inoculations with sporidia of this rust by Bryzgalova [1937] in East Siberia. This species does not occur in India according to Hooker [1875] and Collett [1921].

Recently, Sâvulescu [1938] stated that *Thalictrum* was not found to be infected with brown rust in Rumania. This author was able to infect *T. flavum*, *T. aquilegifolium*, *T. bauhini* and *T. minus*, out of which, well developed aecidia were produced on the first named species only.

As recorded in Part One, occurrence of aecidia on some of the species of *Thalictrum* was reported in India by Barclay [1887]. Aecidial stages of *P. persistens* Plowr. and *P. pruni-spinosae* Pers. have been recorded to occur on *T. flavum*, *T. minus* and some other species of this genus, by Grove [1913]. Butler and Bisby [1931] also referred to the presence of *Aecidium urceolatum* Cke. on this host. Arthur and Cummins [1933] identified the aecidial material collected by R. R. Stewart from Kashmir as *P. Rubigo-vera* (DC.) Wint. There is no experimental evidence, however, of the connection between those specimens and the brown rust of wheat.

In a previous article the writer [Mehta, 1933] stated that inoculations on wheat made on several occasions with aecidiospores occurring in nature on *T. javanicum* near Simla always gave negative results.

13. Germination of teleutospores

Butler [1918] observed that teleutospores are not produced by *P. triticina* as a rule and that their formation depends on special climatic conditions. The writer [Mehta, 1933] stated that the teleutostage of this rust is very scarce in this country and often impossible to obtain. During these studies, no teleuto-material of *P. triticina* could be obtained from the crops at Simla or Narkunda. Till the year 1933, all attempts to germinate the teleutospores of this rust collected from the crop at Almora were unsuccessful, in spite of artificial freezing followed by several dryings and wettings, alternately. Successful germination of teleutospores of this rust was first obtained in January, 1934, in the case of material collected from self sown plants near Simla in November, 1933, which was stored in a refrigerator and frozen for 12 days. Since then, the teleutostage of this rust, like that of *P. graminis* has been raised artificially in miniature plots at Simla during early winter, from year to year, for inoculation experiments on *Thalictrum.*

14. Inoculation experiments

A fairly large number of inoculations was made, from time to time, simultaneously on the different species of *Thalictrum* under study. *T. flavum* (foreign) was always used as a control. All the experiments, results of which are shown in Tables XVIII and XIX, were carried out in the cool greenhouse during cold weather since the year 1935. Aecidiospores from every species that developed aecidia were put on wheat and, as expected, the uredostage of *P. triticina* was produced.

TABLE XVIII

Summary of results of inoculations made, from time to time, on plants of Thalictrum flavum, T. Delavayi *and* T. minus, *raised from foreign seed, with germinating teleutospores of* P. triticina

Column 1=Species of *Thalictrum*
Column 2=Age of leaves in days
Column 3=Total number of leaves inoculated
Column 4=Total number of leaves on which spermogonia appeared
Column 5=Total number of leaves on which nectar was mixed
Column 6=Total number of leaves on which aecidia appeared
Column 7=Nature of infection

1	2	3	4	5	6	7
T. flavum ...	5	8	8	8	8	Heavy
	7	13	12	12	12	Heavy
	5—7	186	138	125	117	Heavy
	10	29	None	...	...	No infection

TABLE XVIII—*contd.*

1	2	3	4	5	6	7
T. Delavayi ...	3	18	18	18	None	Only a few spermogonia
	5	17	17	17	,,	Only a few spermogonia
	7	5	5	5	,,	Only a few spermogonia
	5—7	113	35	35	,,	Only a few spermogonia
	10	32	None	...	...	No infection
T. minus ...	3	18	18	18	None	Only a few spermogonia
	5	18	18	18	,,	Only a few spermogonia
	7	20	15	15	,,	Only a few spermogonia
	5—7	79	13	13	,,	Only a few spermogonia
	10	24	None	...	...	No infection

TABLE XIX

Summary of results of inoculations made, from time to time, on plants of Thalictrum javanicum, T. foliolosum ***and*** T. neurocarpum, (*transplanted indigenous plants*) ***with germinating teleutospores of*** P. triticina.

Column 1=Species of *Thalictrum*
Column 2=Age of leaves in days
Column 3=Total number of leaves inoculated
Column 4=Total number of leaves on which spermogonia appeared
Column 5=Total number of leaves on which nectar was mixed
Column 6=Total number of leaves on which aecidia appeared
Column 7=Nature of infection

1	2	3	4	5	6	7
T. javanicum ...	5	8	8	8	5	Light
	7	5	5	5	5	Light
	5—7	130	97	27	14	Light
	10	24	None	...	...	No infection

TABLE XIX—*contd.*

1	2	3	4	5	6	7
T. foliolosum ...	5	18	18	13	16*	Moderate
	7	17	15	15	15	Moderate to heavy
	5—7	120	98	98	82	Moderate to heavy
	10	29	None	...	...	No infection
T. neurocarpum ...	3	15	15	15	None	Only a few spermogonia
	5	10	10	10	,,	Only a few spermogonia
	7	25	23	23	,,	Only a few spermogonia
	5—7	108	59	54	,,	Only a few spermogonia
	10	8	None	...	...	No infection

* Evidently, aecidia appeared on some of the leaves on which no nectar was mixed, due to coalescence of spermogonia lying side by side because of mass inoculations with sporidia, as stated under Material and Methods.

The results shown in the above tables are summarized below. Information from literature, if available, regarding the reaction of each species to *P. triticina* as well as its distribution in the hills of India is also given :—

(i) *Thalictrum flavum* (foreign).

As recorded by Jackson and Mains [1921], this species was found to be the most susceptible. Copious formation of aecidia took place, during these studies, on fresh leaves up to the age of 7 days. No infection occurred on leaves 10 days old. It is not possible to compare these results with those obtained by other workers because no information is available regarding the age of leaves that were infected by Jackson and Mains [1921], Waterhouse [1932] or Săvulescu [1938]. It is necessary to point out that this species does not occur in India and, as stated in Part One, it was raised from seed obtained from Switzerland.

(ii) In the case of *T. Delavayi* (foreign) only spermogonia were formed on leaves up to the age of 7 days, although leaves as young as 3 days were also inoculated. Like *T. flavum*, this species is not found in this country and was raised from Swiss seed. Jackson and Mains [1921] found this species to be susceptible and obtained aecidia on it.

(iii) As a result of inoculations on *T. minus* (foreign) only spermogonia were formed, during these studies, on leaves up to the age of 7 days. No aecidia were formed even on younger leaves, i.e. 3 days old. Jackson and Mains [1921]

recorded only a weak development of aecidia but usually only spermogonia and sometimes no infection at all on this species. Eremeyeva [1924] and Săvulescu [1938] also failed to obtain the formation of aecidia on this species. It is found in India and is reported to grow at altitudes of 9,000-12,000 ft. in the inner valleys of Temperate Himalayas by Hooker [1875]. The plants used in these studies were also raised from seed obtained from Switzerland.

(iv) *T. javanicum* (indigenous) transplanted from Simla, has been found to be weakly susceptible and aecidia were formed only occasionally on leaves up to the age of 7 days. Even younger leaves, i.e. 5 days old, did not show a better development of aecidia. This species is not included in the list of plants inoculated by Jackson and Mains [1921]. Its distribution as given by Hooker [1875] is 6,000-12,000 ft. in Temperate Himalayas.

(v) *T. foliolosum* (indigenous) transplanted at Simla, has also been found to show variable infection, from moderate to heavy. Aecidia were formed on leaves up to the age of 7 days. No information is available in literature regarding its reaction to *P. triticina*. In Hooker's flora [1875] its distribution is recorded to be 5,000-8,000 ft. in the Himalayas.

(vi) In the case of *T. neurocarpum* (indigenous) obtained from Narkunda, only spermogonia were formed on leaves up to the age of 7 days. No aecidia were produced even on leaves 3 days old. There is no information in literature regarding the reaction of this species either. It is reported to occur in India by Collett [1921] at altitudes of 8,000-10,000 ft. It is a synonym of *T. reniforme* Wall. as recorded by Hooker [1875]. Photographs of the three species on which aecidia were formed are given in Plates XI and XII.

15. General discussion

Like *Berberis*, this host is not found in the plains of India, yet brown rust of wheat recurs year after year in almost every province. It is, therefore, necessary to examine how far species of *Thalictrum* growing in the hills are responsible for outbreaks of this rust, directly in the plains or following an earlier attack in the hills. In general, the factors affecting the formation of viable teleutospores, their germination and subsequent infection of this host are similar to those that have been fully discussed in Part Two. It is unnecessary, therefore, to repeat all those details and only a brief account is given under the following heads :—

(i) Germinability of teleutospores found in nature :—

As stated before, the teleutostage of this rust is rather scarce. It has not been found on the crop at Simla or Narkunda during the last eight years and the material obtained from the crop at Almora (nearly 5,500 ft.) did not germinate

It may be safely concluded from the results of germination tests given in Tables XX-XXII that, as in the case of black rust, it is the teleutospores formed on the crop or self-sown plants, during the cold weather, that are viable.

TABLE XX

Detailed information regarding the various collections of Teleutospores of P. triticina *Eriks. from self-sown plants and miniature plots of wheat at Simla, their storage, further treatment and germination. All germination tests were made at 50°-65°F.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From self-sown plants exposed to sun; collected from Simla in November, 1933; kept in a refrigerator (at 40°-50°F.)	Frozen artificially for 12 days followed by 2 dryings and wettings, each for 2 days	40 per cent	Germination was tested in January, 1934
2	From self-sown plants exposed to natural conditions; collected from Simla on 31st January, 1934	No artificial freezing was done; put for germination, directly after collection	40 per cent	Germination was tested in February, 1934. There were two snow falls during December, 1933-January, 1934
3	Part of the above material, kept in a refrigerator (at 40°-50°F.)	Frozen artificially for 7-10 days followed by one drying and wetting, each for 2 days	60-80 per cent	Germination was tested several times during February-May, 1934
4	From miniature plot; formed in October-November 1934; collected on 20th November, 1934	Frozen artificially for 7 days followed by 3 days' wetting	60 per cent	Germination was tested in November, 1934, directly after collection
5	From miniature plot; formed in winter of 1934-35; collected on 1st March, 1935; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7-20 days followed by one drying and wetting, each for 2 days	50-90 per cent	Germination was tested several times during March-April, 1935
6	From miniature plot; formed in winter of 1935-36; collected on 15th January, 1936; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 10-15 days followed by prolonged wetting for 2-5 days	30-50 per cent	Germination was tested several times during January-March, 1936
7	From miniature plot; formed in winter of 1936-37; collected in January, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7-15 days followed by prolonged wetting for 3-7 days	60-80 per cent	Germination was tested several times during January-March, 1937

In this table, only germination as observed before prolonged storage, has been recorded. Considerable variations in the germinability of these collections were noticed from time to time, when tested for inoculations on the alternate host.

A

Thalictrum flavum, leaves seven days old at the time of inoculation ×5

B

T. foliolosum, leaves seven days old at the time of inoculation ×5

Thalictrum javanicum, leaf 7 days old at the time of inoculation × 1

Table XXI

Detailed information regarding the various collections of Teleutospores of P. triticina *Eriks. from wheat crop in the Nilgiri and Palni hills, their storage, further treatment and germination. All germination tests were made at 50°-65°F.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From crop at Laurudupuram (6,800 ft. above sea level in the Palni hills); collected on 15th November, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 10 days, followed by wetting for 5 days	80 per cent	Germination was tested in January, 1938
2	From crop at Ketti (6,800 ft. above sea level in the Nilgiris); collected on 22nd December, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days, followed by 5 days' wetting	40 per cent	Germination was tested in January, 1938
3	From crop at Kuruthukuzhi (6,900 ft. above sea level in the Nilgiris); collected on 19th December, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days, followed by 5 days' wetting	50 per cent	Germination was tested in January, 1938
4	From crop at Kodaikanal (7,000 ft. above sea level in the Palni hills); collected in November, 1937; kept in a refrigerator (at 40°-50°F.) at Simla	(a) Frozen artificially for 10 days followed by wetting for 5 days	60 per cent	Germination was tested in January, 1938
		(b) No artificial freezing was done. The material was put for germination after storage in a refrigerator for nearly 2½ months	40 per cent	Germination was tested in February, 1938

Table XXII

Detailed information regarding collections of Teleutospores of P. triticina *Eriks. from five places differently situated, their storage, further treatment and germination. All germination tests were made at 50°-65°F.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
1	From crop sown in October, 1934, at Gorakhpur; collected on 31st December, 1934; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 7 days, followed by 1 drying and wetting, each for 2 days	40 per cent	Gorakhpur is situated at the foot-hills of Nepal. Germination was tested in February, 1935
2	From crop sown in July-August at Chitaldroog (2,500 ft. above sea level); collected on 15th December, 1933; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 6 days, followed by 2 dryings and wettings, each for 2 days	None	Germination was tested in April, 1934
3	From crop sown in August-September, 1936, at Wangla (4,000 ft. above sea level) in Nepal; collected on 6th December, 1936; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 12 days, followed by 1 drying and wetting, each for 2 days	40 per cent	Germination was tested in January, 1937

TABLE XXII—*contd.*

No.	Time of collection of the material, its storage, etc.	Further treatment	Germination	Remarks
4	From self-sown plants at Mahabaleshwar (4,500 ft. above sea level); collected on 31st May, 1934 and brought to Simla in an ice-box; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 8 days, followed by 1 drying and wetting for 2 and 5 days, respectively	None	Germination was tested in June, 1934
5	From crop 1932-33 at Muktesar (7,600 ft. above sea level); collected on 21st May, 1933; kept in a refrigerator (at 40°-50°F.) at Simla	Frozen artificially for 5 days, followed by 2 dryings and wettings, each for 2 days	None	Muktesar is situated in the Kumaon Hills. Germination was tested during August, 1933

(ii) Influence of weather conditions on the germination of teleutospores and subsequent infection of *Thalictrum* :—

In the light of what has been discussed in Part Two, germination of teleutospores of this rust also is very unlikely, over the greater part of the hills, during March-May on account of general dryness of the weather. There is a greater likelihood of teleutospores formed during the cold weather at higher altitudes germinating during the monsoon, because those formed at lower altitudes are sure to be killed during the months of April-June, due to hot weather. The question that naturally arises, and which has been fully examined in Part Two with reference to black rust is, would the infection of *Thalictrum* as late as June-August be of any consequence to the wheat crop which is ready for harvest by that time? In this connection, it is important to mention that aecidia on *Thalictrum* have never been found, during these studies, in the neighbourhood of Simla before August. Aecidial material collected by Stewart and identified by Arthur and Cummins [1933] as *P. rubigo-vera* was obtained during July. There is no information in literature regarding the range of temperature or humidity most suitable for the germination of teleutospores of this rust, in particular. During these studies, environmental conditions that gave best results in experiments with teleutospores of black rust were employed and proved to be equally satisfactory. As far as the writer can see, infection of *Thalictrum* is likely to take place only at higher altitudes, during monsoon, except at such localities where weather conditions during March-May may be more favourable than described above.

(iii) Outbreaks of brown rust of wheat in the plains of India :—

There is no case on record, with necessary data, connecting an outbreak of this rust on wheat with diseased *Thalictrum*, in any country. Arthur [1929] stated that the full rôle of the aecial stage of *P. rubigo-vera tritici* (the leaf-rust of wheat) is unknown, as it has not yet been recognized with certainty from field collections and that the aecial stage is not essential to the propagation of the rust as the

species is able to overwinter in the uredinial stage. During these studies either, no evidence could be obtained of the initial attack of this rust on wheat starting from its alternate host and, as stated before, inoculations with aecidiospores from the latter occurring in nature failed to infect wheat. In the plains of India, near the foot-hills, this rust has been found to break out, year after year, at several places as early as December-January on the new crop sown in October-November. As stated above, the earliest period of the infection of *Thalictrum* in the hills, even under the most favourable conditions, would be March-April and that is the time when the wheat crop in the plains over the greater part of the country is actually harvested. After ten years' study of the factors concerned in the annual recurrence of rusts in India, the writer [Mehta, 1933] observed that as far as the plains are concerned, species of *Thalictrum*, the alternate host of brown rust of wheat, seem to play little part in the yearly origin of that rust. Further, that this rust is, in all probability, disseminated to the plains from comparatively low altitudes where, on account of a milder winter, its uredospores occurring at the time of sowing, cause outbreaks on the new crop rather early in the season.

Oversummering of this rust like the other two of wheat, in the uredostage in the hills of India has been repeatedly recorded by the writer. Reference was also made by the writer [Mehta, 1933] to the existence of several foci of infection in the hills in the north and some in the south as well. Since then, well-advanced infection on the early crop, sown in August-September, at altitudes of 4,000-5,000 ft. in Central Nepal has been found with this rust during December. In one case, as much as 20-40 per cent crop infection was observed in the first week of that month. It may also be mentioned that the earliest outbreaks of this rust in the plains of the United Provinces were noticed, year after year, near the foot-hills along the Nepal border.

In the Nilgiris, this rust, like the black, is found all the year round in the uredostage, i.e. on the crops (there are two in the course of the year) or on self-sown plants, tillers, etc., during the intervening period. There is abundance of this rust in the Nilgiris, year after year, by August-September on the first crop (sown in April-June).

The possibility of the infection of wheat in the plains even earlier than December-January has been recently demonstrated by 'out of season' sowings done at the request of the writer. At Mandya (Mysore) this rust was found in traces as early as October 16th, 1935 on wheat sown in August, i.e. nearly two months before time. In the year 1937, it broke out at Coimbatore, in the miniature plot of wheat sown during June-July, as early as the 28th September. By the circuitous hills path, Mandya and Coimbatore are only 128 and 50 miles respectively from Ootacamund (Nilgiris).

In the Northern hills, it is difficult for this rust also, to spread fast from plant to plant during the cold weather at altitudes of nearly 6,000 ft. and above. At Simla, in one of the experiments the length of the incubation period, in the

case of inoculated seedlings kept in the open, was found to be 20 days, during December-January.

Whereas, oversummering of this rust in the uredostage at comparatively low altitudes (4,000-5,000 ft.) is an established fact, infection of *Thalictrum*, prior to its outbreak on the new crop in November-December, is very unlikely at such heights because germinable teleutospores could hardly be produced before that period and those formed on the previous crop in May-June would be ineffective due to exposure during summer. It is obvious, therefore, that as in the case of black, outbreaks of this rust in the plains have little connection with the infection of its alternate host in the hills.

(iv) Production of New Physiologic Races on *Thalictrum* :—

Formation of new physiologic races by hybridization on *Thalictrum* should be as likely as on barberries. There is, however, only one case on record in which Waterhouse [1932] obtained two new races as a result of mass inoculations with sporidia of this rust. During these studies, five inoculation experiments were made on wheat, with the aecidiospores of this rust produced artificially by mass inoculations with sporidia on *Thalictrum*, but no new race was found in the uredo-material thus formed. In these inoculations, the nectar from spermogonia was mixed at random in almost every case. In Section I, it has been stated that so far only six races of this rust have been found in India. They are 10, 20, 63, A, B and C, the last three have not been reported from any other country and are not included in the latest key of ninety races, compiled by Humphrey, Johnston and Caldwell in the year 1936.* As in the case of black rust, the occurrence of such a small number of races is a strong proof of the fact that *Thalictrum* is not playing an important rôle in the annual recurrence of this rust. It is difficult otherwise to explain, why, in the presence of a large number of *Thalictrum* plants in the hills of India, two species of which have proved to be susceptible and there may be some more, the number of physiologic races should be so small. It is necessary to point out that out of a total of 408 collections that have been analysed, 116 were obtained from hills and hilly tracts, although the area under wheat in the hills covers less than 5 per cent of the total acreage.

As pointed out in the general discussion under black rust, infection of *Thalictrum*, although likely, does not seem to be of common occurrence in this country. Further, that new races even though formed from time to time do not seem to infect wheat, as is clear from the small number of races found even in the hills.

(v) Control of brown rust of wheat by the destruction of *Thalictrum* :—

A good deal of what has been said regarding the eradication of barberries applies to the alternate host of this rust as well. In the absence of any evidence

* Intimation has just been received that International numbers 106, 107 and 108 respectively have been assigned to races A, B and C in the revised list issued by those authors in January, 1939, dealing with 108 races.

of the initial attack of this rust on wheat starting from diseased *Thalictrum*, the question of its eradication does not arise.

(vi) Conclusion :—

In conclusion, it may be stated that, as in the case of black rust, the real source of infection to the wheat crop, from year to year, is the uredostage commonly found to be oversummering in the hills and not *Thalictrum* which may get infected, if at all, long after the harvest in the plains as well as over the greater part of the hills.

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Summary

17. Part one

In India, *Berberis* and *Thalictrum*, alternate hosts of *P. graminis* Pers., the black rust of cereals and grasses and *P. triticina* Eriks. the brown rust of wheat respectively, are restricted to the hills.

Successful germination of teleutospores of black and brown rusts of wheat was obtained, for the first time in this country, during the course of these studies, in the years 1933 and 1934, respectively.

On account of the scarcity of viable teleuto-material on crops even in the hills, seedlings of wheat were inoculated, from year to year, in July-August in miniature plots at Simla, in order to obtain adequate supply, for experimental work, of germinable teleutospores early in winter, when the range of temperature for their formation is most suitable.

For inoculations on alternate hosts, it was felt necessary to construct a greenhouse with double glass walls and roof, so as to control temperature within the range prevailing during spring in temperate climates. In addition, cool air had to be introduced into this greenhouse on sunny days. Construction of the greenhouse, methods of study as well as other devices adopted for the control of temperature have been described in detail.

18. Part two

Large number of inoculations with sporidia of black rust of wheat were made simultaneously on the more common species of *Berberis*. *B. vulgaris* Linn. (foreign) or *B. lycium* Royle, an indigenous species that was found to be moderately susceptible, was used as control in all the experiments.

As elsewhere, *B. vulgaris* Linn. was very heavily infected but leaves older than 12 days proved to be resistant. This species does not occur in India.

B. lycium Royle, showed variable reaction, light to heavy infection. On the whole, fresh leaves up to the age of 10 days proved to be moderately susceptible.

B. aristata and *B. coriaria* developed aecidia on leaves up to the age of 8 days in the case of seedlings only.

B. petiolaris, Syn. *B. vulgaris*, var. 1. *vulgaris* proper, according to Hooker, (*B. pachyacantha* Koehne) was found to be highly resistant. *B. umbellata* ? (Swiss) showed a similar reaction.

With regard to the hitherto unsettled rôle of barberries in India, it may be observed that :—

(i) Normally, there is scarcity of germinable teleuto-material available from the crops over the greater part of the area under wheat and barley, even in the hills of India, due to their formation in or subsequent exposure to the hottest part of the year (April-June).

(ii) Viable teleutospores are likely to be found on crops at higher altitudes. Teleutospores produced on self-sown plants and tillers during winter at such altitudes should also be germinable.

(iii) On account of general dryness of the weather in March-May, germination of teleutospores and subsequent infection of barberries is more likely at the higher altitudes, during the earlier part of the monsoon (June-July) but such infection would be of little consequence to the crops that are reaαy for harvest by that time.

(iv) Black rust has been found to break out, year after year, at several places in the plains as early as December-January, 3-4 months prior to the period of earliest possible infection of barberries in the hills and there are none in the plains.

(v) Well-advanced infection with this rust has been observed in the hills in north as well as the south on early crops, long before its outbreak in the plains. Wheat sown at writer's request ' out of season ' at foot-hills got infected as early as September-October, 2-4 weeks before the normal period of sowing in the plains.

(vi) There is no case on record, nor could any evidence be obtained during these studies, of an outbreak of this rust starting from barberries.

(vii) At higher altitudes, the rust under reference is unable to spread from plant to plant during winter because of severe cold. It has not been observed on the crop before March.

(viii) Black rust is disseminated to the plains of India from comparatively low altitudes, where, on account of the presence of oversummering uredospores at the time of sowing, it breaks out on the new crop rather early in the season and due to mild weather is also able to spread fast from plant to plant. During these studies, two important foci have been located, where, on account of early sowing, there is plenty of inoculum by the time wheat and barley are sown in the plains.

(ix) The previous contention of the writer that, as far as the plains are concerned, barberries have little part to play in the annual recurrence of black rust, has been very strongly corroborated by recent studies.

(x) For the reasons given above, the writer is fully convinced that in this country, eradication of barberries would be thoroughly inadvisable. Notwithstanding the cost of millions of rupees over such a project, it is obvious that outbreaks of black rust will still recur unabated, originating as they do, largely from uredospores that oversummer in the hills.

Besides, there are two other rusts, the brown and yellow, which are equally common over the greater part of the country and, like the black, start from the hills every year. Eradication of barberries, therefore, is not at all likely to save the wheat crop from epidemics of rusts.

Recent studies of physiologic races of wheat rusts in this country have revealed a very important fact, which shows that infection of barberries and, at any rate, of cereals therefrom, is not of frequent occurrence. So far, only six races of this rust have been found. If barberries were playing an important rôle, it is difficult

to explain why the production of new races by hybridization, a phenomenon of wide occurrence in other parts of the world, should have been in abeyance in this country, in the presence of millions of those bushes in the hills.

(xi) The most obvious source of infection of wheat and barley with black rust, from year to year, is the uredostage commonly found to be oversummering in the hills and not the post-epidemic infection of *Berberis*, if at all, in restricted areas at the higher altitudes.

19. Part three

Large number of inoculations with sporidia of brown rust of wheat were made simultaneously on the more common species of *Thalictrum*, using *T. flavum*, (foreign) as a control in every experiment. The latter was found to be heavily susceptible, as elsewhere.

Aecidia were also formed on two indigenous species, *T. javanicum* and *T. foliolosum*. Out of these, the former showed only weak infection. In the case of *T. Delavayi* and *T. minus*, both raised from foreign seed, only spermogonia were formed. One of the indigenous species, *T. neurocarpum* showed a similar reaction.

With regard to the rôle of *Thalictrum* in fresh outbreaks of brown rust of wheat, it may be observed that :—

(i) Teleutostage is rather scarce and normally, no germinable material is available over the greater part of the area under wheat, even in the hills. Viable teleutospores are likely to be found on the crop at higher altitudes as well as on self-sown plants and tillers early in winter.

(ii) As in the case of barberries, infection of *Thalictrum* is more likely at higher altitudes during the earlier part of monsoon than in spring, when the weather is rather dry. Infection of *Thalictrum*, as late as the monsoon, June-July should be of little consequence to the wheat crop which is ready for harvest by that time.

(iii) Observations made regarding the early appearance of black rust in the plains of India, also apply, in a general way, to this rust.

(iv) There is no case on record, nor could any evidence be obtained during these studies, of an attack of this rust on wheat starting from *Thalictrum*.

(v) Outbreaks of this rust also are, in all probability, caused in the plains by the dissemination of uredospores from comparatively low altitudes where it appears rather early in the season. Two important foci in the hills, where, on account of early crops, there is considerable inoculum at the time of sowing in the plains, have been located during these studies. The alternate host, therefore, seems to play little part in the annual recurrence of this rust in the plains.

(vi) Infection of wheat from *Thalictrum*, although possible, does not seem to be of common occurrence. This is fully borne out by the fact that so far only six physiologic races of brown rust have been found to occur. If species of *Thalictrum* were playing an important rôle in the life-history of this rust, it is obvious that, as a result of hybridization, the number of physiologic races, at any rate in the hills, should have been very large.

(vii) In view of the simultaneous oversummering of yellow and black rusts in the hills, destruction of *Thalictrum* is not at all likely to save the wheat crop from devastating epidemics caused by rusts in general, as at present.

(viii) As in the case of black rust, the real source of infection to the wheat crop from year to year is the uredostage commonly found to be oversummering in the hills and not *Thalictrum* which may get infected, if at all, long after the harvest in the plains as well as over the greater part of the hills.

Appendix A

Weekly Average maximum and minimum as well as the Highest and Lowest temperatures in shade during each week in the month of March, 1934 and 1935 at Agra

Year	Period	Weekly average		Highest	Lowest
		Maximum	Minimum		
1934	1st-7th March ...	82.9°F.	51.3°F.	88°F.	46°F.
	8th-14th March ...	76.4°F.	53.7°F.	83°F.	46°F.
	15th-21st March ...	84.6°F.	53.6°F.	91°F.	48°F.
	22nd-28th March ...	93.1°F.	59.3°F.	96°F.	58°F.
	29th-31st March ...	96.7°F.	60.3°F.	100°F.	55°F.
1935	1st-7th March ...	81.6°F.	48.0°F.	84°F.	43°F.
	8th-14th March ..	90.9°F.	52.9°F.	98°F.	48°F.
	15th-21st March ...	96.3°F.	58.6°F.	100°F.	53°F.
	22nd-28th March ...	95.0°F.	62.9°F.	100°F.	56°F.
	29th-31st March ...	86.3°F.	54.7°F.	89°F.	50°F.

Appendix B

Weekly Average maximum and minimum as well as the Highest and Lowest temperatures in shade each week in the month of February 1922 and the first two weeks of March 1927 at Pusa

Year	Period	Weekly average		Highest	Lowest
		Maximum	Minimum		
1922	1st-7th February ...	72.8°F.	48.1°F.	74.8°F.	45.2°F.
	8th-14th February ...	78.4°F.	48.4°F.	82.2°F.	46.6°F.
	15th-21st February ...	85.4°F.	56.4°F.	86.6°F.	53.3°F.
	22nd-28th February ...	87.3°F.	53.8°F.	90.2°F.	49.4°F.
1927	1st-7th March ...	81.7°F.	50.3°F.	87.6°F.	45.5°F.
	8th-15th March ...	77.4°F.	54.3°F.	83.8°F.	50.0°F.

APPENDIX C

Weekly Average maximum and minimum as well as the Highest and Lowest temperatures in shade each week in the months of May and June during the years 1932-37 at Simla

Year	Period	Weekly average		Highest	Lowest
		Maximum	Minimum		
1932	1st-7th May ...	67.6°F.	50.1°F.	70°F.	43°F.
	8th-14th May ...	66.1°F.	50.3°F.	70°F.	46°F.
	15th-21st May ...	73.4°F.	59.4°F.	77°F.	53°F.
	22nd-28th May ...	76.9°F.	59.3°F.	82°F.	51°F.
	29th May-4th June ...	79.3°F.	65.6°F.	83°F.	62°F.
	5th-11th June ...	77.9°F.	64.6°F.	84°F.	58°F.
	12th-18th June ...	81.4°F.	64.4°F.	87°F.	53°F.
	19th-25th June ...	76.4°F.	61.1°F.	83°F.	54°F.
	26th-30th June ...	77.4°F.	60.8°F.	82°F.	50°F.
1933	1st-7th May ...	59.6°F.	48.6°F.	66°F.	46°F.
	8th-14th May ...	60.1°F.	48.4°F.	68°F.	42°F.
	15th-21st May ...	71.4°F.	57.1°F.	76°F.	52°F.
	22nd-28th May ...	75.4°F.	59.3°F.	79°F.	53°F.
	29th May-4th June ...	76.0°F.	62.4°F.	79°F.	53°F.
	5th-11th June ...	78.3°F.	63.6°F.	80°F.	57°F.
	12th-18th June ...	77.6°F.	62.9°F.	80°F.	58°F.
	19th-25th June ...	72.4°F.	60.1°F.	77°F.	57°F.
	26th-30th June ...	69.6°F.	59.6°F.	70°F.	58°F.
1934	1st-7th May ...	68.0°F.	52.0°F.	72°F.	45°F.
	8th-14th May ...	69.4°F.	51.7°F.	74°F.	43°F.
	15th-21st May ...	72.0°F.	55.0°F.	75°F.	51°F.
	22nd-28th May ...	79.0°F.	62.9°F.	82°F.	55°F.
	29th May-4th June ...	75.7°F.	59.4°F.	81°F.	48°F.
	5th-11th June ...	75.9°F.	60.0°F.	81°F.	52°F.
	12th-18th June ...	79.0°F.	65.0°F.	84°F.	54°F.

APPENDIX C—*contd.*

Year	Period	Weekly average		Highest	Lowest
		Maximum	Minimum		
1934—*contd.*	19th-25th June ...	72.3°F.	59.1°F.	76°F.	56°F.
	26th-30th June ...	69.3°F.	59.0°F.	71°F.	58°F.
1935	1st-5th May ...	72.2°F.	57.8°F.	73°F.	52°F.
	6th-12th May ...	71.1°F.	57.1°F.	75°F.	53°F.
	13th-19th May ...	73.1°F.	59.7°F.	77°F.	54°F.
	20th-26th May ...	77.1°F.	62.1°F.	80°F.	59°F.
	27th May-2nd June ...	81.4°F.	67.4°F.	83°F.	63°F
	3rd-9th June ...	80.1°F.	65.9°F.	84°F.	65°F.
	10th-16th June ...	78.4°F.	59.9°F.	81°F.	52°F.
	17th-23rd June ...	78.3°F.	65.0°F.	83°F.	61°F.
	24th-30th June ...	77.7°F.	61.6°F.	82°F.	52°F.
1936	1st-10th May ...	77.0°F.	61.1°F.	80°F.	54°F.
	11th-17th May ...	76.4°F.	61.9°F.	81°F.	55°F.
	18th-24th May ...	76.0°F.	62.9°F.	79°F.	57°F.
	25th-31st May ...	74.3°F.	62.3°F.	79°F.	55°F.
	1st-7th June ...	72.0°F.	56.6°F.	77°F.	48°F.
	8th-14th June ...	73.9°F.	59.9°F.	76°F.	54°F.
	15th-21st June ...	70.6°F.	60.6°F.	73°F.	59°F.
	22nd-30th June ...	67.0°F.	56.0°F.	70°F.	54°F.
1937	1st-9th May ...	67.1°F.	52.8°F.	73°F.	46°F.
	10th-16th May ...	70.4°F.	59.6°F.	80°F.	49°F.
	17th-23rd May ...	76.0°F.	59.4°F.	81°F.	50°F.
	24th-30th May ...	78.3°F.	62.1°F.	79°F.	57°F.
	31st May-6th June ...	78.1°F.	66.0°F.	81°F.	63°F.
	7th-13th June ...	75.0°F.	58.0°F.	82°F.	49°F.
	14th-20th June ...	76.9°F.	63.6°F.	82°F.	52°F.
	21st-30th June ...	73.1°F.	61.7°F.	79°F.	58°F.

Appendix D

Monthly Average maximum and minimum as well as the Highest and Lowest temperatures in shade in the months of October-December during the years 1932-37 at Simla

Year	Period	Monthly average		Highest	Lowest
		Maximum	Minimum		
1932	October	64.8°F.	52.5°F.	70°F.	46°F.
	November	60.6°F.	46.9°F.	67°F.	43°F.
	December	51.8°F.	39.9°F.	63°F.	28°F.
1933	October	63.4°F.	50.3°F.	68°F.	42°F.
	November	58.0°F.	45.2°F.	63°F.	36°F.
	December	54.3°F.	40.8°F.	66°F.	32°F.
1934	October	65.3°F.	52.2°F.	72°F.	48°F.
	November	59.0°F.	45.3°F.	65°F.	42°F.
	December	49.3°F.	37.5°F.	62°F.	28°F.
1935	October	64.5°F.	50.9°F.	69°F.	42°F.
	November	58.2°F.	44.8°F.	65°F.	36°F.
	December	49.4°F.	37.5°F.	58°F.	29°F.
1936	October	64.4°F.	51.0°F.	70°F.	42°F.
	November	58.7°F.	45.8°F.	63°F.	40°F.
	December	47.5°F.	36.4°F.	62°F.	27°F.
1937	October	63.8°F.	49.8°F.	71°F.	40°F.
	November	56.0°F.	43.1°F.	63°F.	35°F.
	December	50.1°F.	38.0°F.	60°F.	21°F.

Appendix E

Total rainfall during each week, weekly range and average humidity in March, April and up to the 15th May during the years 1932-37 at Simla

Year	Period			Total rainfall (in inches)	Humidity	
					Range	Average
					Per cent	Per cent
1932	1st-7th March	...	...	T,* twice	21-43	31.7
	8th-14th March	...	..	0.5	25-56	38.6
	15th-21st March	..	..	...	18-38	27.1
	22nd-28th March	...	..	0.5	18-85	47.0
	29th March-4th April	..	...	0.4	27-82	49.4
	5th-11th April	...	...	...	17-33	22.4
	12th-18th April	...	...	0.1	16-48	24.9
	19th-25th April	...	...	...	21-60	31.1
	26th April-2nd May	...	...	0.8	36-68	50.7
	3rd-9th May	...	...	0.4	24-77	44.9
	10th-15th May	...	...	0.2	15-90	39.8
1933	1st-7th March	...	...	...	10-38	24.4
	8th-14th March	...	...	0.2	7-60	25.7
	15th-21st March	...	...	0.4	15-54	36.5
	22nd-28th March	...	...	1.1	7-92	40.7
	29th March-4th April	...	...	T	7-33	18.1
	5th-11th April	...	...	0.1	20-62	39.6
	12th-18th April	...	...	1.0	26-82	46.6
	19th-25th April	...	...	1.7	22-100	52.4
	26th April-2nd May	...	...	0.8	16-93	37.4
	3rd-9th May	...	...	3.1	37-100	64.1
	10th-15th May	...	...	0.6	29-93	58.5

* T indicates less than 0.1 in. of rainfall

APPENDIX E—*contd.*

Year	Period	Total rainfall (in inches)	Humidity	
			Range	Average
			Per cent	Per cent
1934	1st-7th March	0.4	1-76	30.1
	8th-14th March	0.7	22-78	51.3
	15th-21st March	...	20-42	31.0
	22nd-28th March	T, twice	14-45	32.1
	29th March-4th April	..	8-35	23.4
	5th-11th April	0.3	15-48	30.0
	12th-18th April	0.1	12-31	21.6
	19th-25th April	0.8	18-65	34.0
	26th April-2nd May	...	15-42	28.1
	3rd-9th May	0.7	17-58	37.4
	10th-15th May	0.7	7-77	37.5
1935	1st-7th March	0.1	9-60	43.1
	8th-14th March	..	10-30	18.3
	15th-21st March	0.2	11-43	29.3
	22nd-28th March	1.1	20-93	43.7
	29th March-4th April	...	23-70	40.1
	5th-11th April	1.8	29-78	52.0
	12th-18th April	0.4	20-53	35.0
	19th-25th April	..	13-32	25.3
	26th April-2nd May	...	25-48	31.4
	3rd-9th May	T	21-30	25.0
	10th-15th May	T, 4 times	28-39	36.3
1936	1st-7th March	0.3	20-100	41.7
	8th-14th March	0.2	11-78	34.3
	15th-21st March	T	15-38	26.7
	22nd-28th March	0.6	24-70	42.3

APPENDIX E—*contd.*

Year	Period	Total rainfall (in inches)	Humidity	
			Range	Average
			Per cent	Per cent
1936—*contd.*	29th March-4th April	0.9	32-77	57.7
	5th-11th April	1.8	12-79	35.6
	12th-18th April . ..	..	20-39	22.6
	19th-25th April	T, twice	18-66	29.7
	26th April-2nd May	...	12-25	20.8
	3rd-9th May	T, twice	18-42	24.9
	10th-15th May	0.6	20-55	33.0
1937	1st-7th March	T	12-68	33.1
	8th-14th March	...	2-77	30.9
	15th-21st March	...	10-41	24.6
	22nd-28th March	0.4	21-100	38.0
	29th March-4th April	1.8	28-100	52.6
	5th-11th April	0.5	25-54	37.4
	12th-18th April	0.6	20-52	33.1
	19th-25th April	0.5	15-61	26.9
	26th April-2nd May	...	7-40	20.8
	3rd-9th May	0.5	21-59	37.0
	10th-15th May	0.4	39-54	46.3

Data of temperature and humidity quoted in Appendices A and C-E were obtained from the Meteorological department.

SECTION III.—OVERSUMMERING IN RELATION TO ANNUAL RECURRENCE

(With one map)

CONTENTS

1. Introduction

On an average, there are 33 million acres under wheat and another 8 millions or so under barley, each year in India. The bulk of these crops is raised in the plains, where they are sown during October-November and harvested in March-April. In the hills, these crops are grown in small terraces and cover hardly 5 per cent of the total acreage. The time of sowing is the same as in the plains but, on account of cold weather, harvesting is done 1-2 months later.

Over the greater part of the country, wheat suffers from all the three rusts, i.e., *Puccinia graminis tritici* (Pers.) Eriks. & Henn., *P. triticina* Eriks. and *P. glumarum* (Schm.) Eriks. & Henn. *P. graminis tritici*, the black rust of wheat, is also found on barley and so is *P. glumarum*. *P. simplex* (Koern) Eriks. & Henn., the dwarf rust of barley, is very rare in this country. The black rust of oats, *P. graminis avenae* (Pers.) Eriks. & Henn. was first found during the course of these studies and seems to be restricted to the Nilgiris. In this country, oats are cultivated only for purposes of fodder.

In the year 1923, the writer started a study of the Annual Recurrence of Rusts of wheat and barley in the plains of India and his first article on the subject was published six years later [Mehta, 1929]. This was followed by another publication [Mehta, 1933] giving an account of further progress of investigations on the cereal-rust problem of this country.

In this section, only data obtained up to March, 1938, regarding oversummering of rusts in relation to their annual recurrence, have been supplied.

For a period of three years ending with March, 1938, survey of oversummering of rusts and their incidence on crops in the Punjab, Bombay-Deccan and Madras was carried out as a co-ordinated study and the writer is very grateful to Rai Sahib J. C. Luthra, Professor of Botany, Agricultural College, Lyallpur; Dr. B. N. Uppal, Plant Pathologist to the Government of Bombay, Poona; Rai Bahadur S. Sundararaman, late Government Mycologist to the Government of Madras, Coimbatore and his successor Mr. K. M. Thomas for their kind help in the supervision of that work. In the study of oversummering of rusts in relation to their fresh outbreaks in hills as well as the plains, the following members of the Rust Research Staff have rendered valuable assistance:—

Mr. R. Prasad, at present working as Assistant Mycologist in the rust research scheme, Mr. Shyam Lal Sharma, Mr. H. L. Gulatia, now Senior Assistant, Rust Research Laboratory, Simla and Mr. R. P. Malik. In the earlier part of the scheme, Mr. Gopal Singh also assisted in this study. Observations on the incidence of rusts, in the three Provinces mentioned above, were made by Messrs. Dayal Singh, Sikandar Lal Sahgal, B. S. Varadarajan and T. V. Pattabhiraman as well as by some members of the rust research staff working in the main scheme.

2. Scope of the present investigation

The writer [Mehta, 1929] has already referred to the observations made by Butler [1903] and Howard and Howard [1909] on the importance of this study.

Howard and Howard [1909] also stated that the propagation of wheat rusts in India was an un-settled problem and that their control by direct means could be considered only when we knew the course of their life-histories between harvesting and the next sowing. It has already been pointed out [Mehta, 1929; 1931, 1, 2; 1933] that, in the plains of India, there is no local source of infection at the time of sowing. A brief summary of the data obtained from a study of oversummering of the rusts, under reference, in the hills as well as information regarding their outbreaks on the new crops have also been supplied in those articles. Since the year 1933, the scope of the study was extended to include new areas and, from year to year, simultaneous observations were made on the incidence of rusts in the north as well as the south. As before, the object of the study was to obtain as much information as possible regarding the rôle of *Berberis* and *Thalictrum* on one hand and that of oversummering uredospores on the other, in fresh outbreaks on wheat and barley crops in the hills. With regard to the study of incidence of rusts in the plains, due attention was paid also to the dates of their appearance at the foot-hills.

3. Methods of study

Throughout the period under reference, intensive search was made in the hills, as before, for uredospores on self-sown plants of wheat and barley, their tillers and stubble as well as on wild grasses (in the case of black and yellow rusts). In the plains also, wild grasses growing in and near the fields were carefully examined for rusts and so were self-sown plants that are found only at some places along the sea-shore.

In order to obtain the fullest possible information regarding the viability of uredospores all the year round, rust cultures were maintained in miniature plots at Almora (5,500 ft. above sea level in Kumaon hills) for nearly three years as well as at Simla (7,000 ft. above sea level) for a period of seven years. Similar cultures were also grown for shorter periods by special arrangements at Muktesar (7,600 ft.) and Narkunda (9,200 ft. above sea level). At Almora and Simla, *after* the first set of inoculations in each miniature plot, wheat was sown every 2-3 months to secure automatic infection of fresh plants at different times of the year. Fresh inoculations were made, if necessary, *after* prolonged dry weather in order to maintain cultures on a fairly large number of plants throughout the year.

On account of the absence of wheat cultivation in the southern part of Mysore State, the writer made arrangements, by special request, for miniature plots at Bangalore and Mandya (at the foot of the Nilgiris on the north) with the object of finding out the earliest period of rust appearance due to the presence of abundant inoculum in the Nilgiris on the first crop (sown April-June). Similar plots were started at Coimbatore (at the foot of the Nilgiris on the south) in the year 1937. The writer supplied seed of Agra local wheat, a very susceptible variety, for all these miniature plots and it was purposely sown 'out of season', i.e., during August at Mandya and Bangalore and June onwards at Coimbatore.

4. Review of literature

A discussion on the chief sources of initial infection of cereals by rusts is outside the scope of this section. In two previous articles, the writer [Mehta, 1923; 1929] reviewed early and contemporary work on that subject and also discussed the relative importance of the factors concerned in the annual outbreaks of rusts, with special reference to the plains of India in the latter.

In recent years, considerable amount of evidence of the survival of rusts in the uredostage on self-sown plants and tillers, during the critical period, has been obtained from almost all the important wheat growing countries of the world. It is obvious that, on account of climatic differences, the incidence of rusts at any time of the year may not be similar in any two countries. Over the greater parts of Europe and North America, the period most critical for the survival of uredospores is the intensely cold winter. In tropical countries, on the other hand, it is the heat of summer that seriously affects the uredostage of rusts. On the whole, rusts flourish best in mild weather and it may be said that, as a rule, heat does more harm to the uredospores than severe cold. With regard to the possible rôle of uredospores in fresh outbreaks, the first thing one has to enquire, therefore, is, whether the rust in question can or cannot survive on its original or a collateral host, during the unfavourable period, winter or summer, as the case may be.

Plowright [1882] stated that in England, uredospores of *P. rubigo-vera* are found all the year round. Overwintering of *P. rubigo-vera* in the uredostage was reported from U. S. A. by Hitchcock and Carleton [1894], Bolley [1898] and Carleton [1899]. Klebahn [1904] stated that *P. dispersa* can overwinter in the uredostage in Germany and Ward [1905] made a similar observation regarding the rust on Bromes. The writer [Mehta, 1923], Ducomet [1925, 1927], Roussakov [1926], Shitikova-Roussakova [1927] and Arthur [1929], reported the overwintering of *P. triticina*, the brown rust of wheat, in England, France, U. S. S. R. and the United States of America, respectively. Sâvulescu [1933] observed that *P. triticina* can overwinter in the uredostage and as resting mycelium in Rumania, except during severe winters. Asperger [1935] stated that in the neighbourhood of Vienna, survival of uredospores of this rust is possible specially after mild winters. Recently, Sibilia [1937] recorded the frequent occurrence of the uredostage of this rust on self-sown and early wheat in Northern and Central parts of Italy.

Overwintering of *P. glumarum* also, in the uredostage, has been recorded from Germany, England, Pacific Coast of U. S. A., France and U. S. S. R. respectively, by Klebahn [1904], the writer [Mehta, 1923], Hungerford [1923], Ducomet [1925, 1927] and Roussakov [1926]. Sanford and Broadfoot [1932] pointed out that uredospores of this rust are capable, at least occasionally, of surviving the winter in Alberta (Western Canada).

In the case of *P. graminis*, it is interesting to note that evidence of overwintering of uredospores has been obtained only in such countries, or parts thereof, as have a comparatively mild winter. For instance, Stakman [1927] stated that

this rust is able to overwinter only in some of the Southern States of U. S. A. Shitikova-Roussakova [1927] and Peltier [1929] recorded the overwintering of this rust in North Manchuria and the Southern States of U. S. A. respectively. The writer [Mehta, 1933] reported that all the three rusts of wheat are able to overwinter in the uredostage in the hills of India. Recently, Sibilia [1937] observed that *P. graminis* occurs in the uredostage on self-sown and early wheat, rather frequently, in northern and central parts of Italy.

Similarly, there is conclusive evidence of oversummering of wheat rusts in the uredostage in cooler localities of those countries, where the summer is rather hot. McAlpine [1906] stated that uredospores of black rust of wheat can oversummer in Australia. In India, Burns [1909 ; work not published] inoculated some susceptible varieties of wheat with *P. graminis* during summer, under the shade of a mango tree at Poona (1,834 ft. above sea level) in the month of May and the rust appeared after five weeks. The average maximum temperature in shade during the period of the experiment was 99.3°F. There is no evidence, however, of its oversummering at Poona under natural conditions.

The writer [Mehta, 1925] reported the survival of uredospores of brown and yellow rusts of wheat in the hills during summer, because of favourable weather. Later, Mehta [1929] observed that all the three rusts of wheat can oversummer at various altitudes in the hills of India. Waterhouse [1929] stated that in Australia black as well as brown rusts are almost certainly present all the year round in the uredostage in wheat-growing areas. Bensaude [1930] stated that probably the uredospores of *P. graminis* are unable to withstand the summer heat in the vicinity of Lisbon as well as in the low-lying parts of Portugal but are found during summer only in the mountains, as in India. In a later article, the writer [Mehta, 1933] gave additional information regarding oversummering of all the three rusts of wheat as well as of black and yellow rusts of barley in the hills of India.

5. Oversummering of *P. graminis* Pers.

After five years' study of the incidence of *P. graminis tritici* (Pers). Eriks. & Henn., the black rust of wheat in the Kumaon and Simla hills, the writer [Mehta, 1929] gave a summarized account of its oversummering in the uredostage. Since the year 1930, the area of this study has been extended from time to time. In general, it may be stated that this rust has been found to oversummer in almost all the hills visited excepting Pachmarhi (Central Provinces). It has already been stated by the writer [Mehta, 1933] that in the Kumaon hills volunteer wheat was found to be infected at an altitude as low as 3,200 ft. on the banks of a river during June, the hottest month of the year. Since then, evidence of its oversummering in the uredostage has been obtained from Nepal, Kashmir, Western Ghats, the Dangs and Eastern Ghats. Further evidence of the presence of all the three rusts of wheat in abundance in the Nilgiris and their occurrence in the

MAP OF INDIA No. 4

SCALE 1 INCH = 384 MILES

Palni hills, practically all the year round, because of two crops, one sown in April-June and the other during August-October, has been collected.

The writer is fully convinced that black rust should be able to oversummer normally at altitudes of 4,500 ft. and above and that it is likely to oversummer, at least occasionally, even at lower altitudes, i.e. 3,000-4,000 ft. at such localities as are adequately protected from direct sun by favourable aspect or on account of natural irrigation. In short, the survival of this rust in the uredostage during summer should be anticipated under moist conditions at all such localities, where the maximum shade temperature does not exceed 95°-100°F., from day to day. Uredospores of *P. graminis avenae* (Pers.) Eriks. & Henn., the black rust of oats, have been found in the Nilgiris, practically all the year round, on crops, first as well as second, self-sown plants, tillers, etc. As stated before, in India this rust seems to be restricted to the Nilgiris. Relevant information regarding collections of viable uredo-material of *P. graminis tritici* occurring on self-sown wheat, barley or their tillers, during summer at different places in the hills, is given in Tables I-IX. Hills and hilly tracts of India are shown in Map No. 3 of Section II. The boundaries of different provinces and states as well as important stations in the plains, mentioned in this section, are shown in Map No. 4.

6. Oversummering of *P. triticina* Eriks.

An account of oversummering of *P. triticina* also in the Simla and Kumaon hills was published by the writer [Mehta, 1929]. In a later article [Mehta, 1933,] it was stated that this rust was found at several places on the banks of a river in Kumaon hills at altitudes of 3,500-4,000 ft. during May-June, the hottest part of the year. Evidence of oversummering of this rust has, since then, been obtained from a large number of hill stations in other parts of the country also. Its presence in the uredostage, practically all the year round, on the wheat crop in the Nilgiris and Palnis has also been observed. Like the black, this rust seems to be able to survive in the uredostage, normally at altitudes of 4,500 ft. and above and under protection or natural irrigation it may oversummer, at least occasionally, at places slightly lower than 4,000 ft. On the whole, it has been found to oversummer at localities slightly cooler than those which only the black rust can stand. Relevant information regarding collections of viable uredo-material of *P. triticina* occurring on self-sown wheat or its tillers during summer at different places in the hills is given in Tables I-VI, VIII and IX.

7. Oversummering of *P. glumarum* (Schm.) Eriks. & Henn.

As stated in two earlier articles [Mehta, 1929; 1933] this rust does not normally oversummer below altitudes of 6,000 ft. It has been found in the uredostage, practically all the year round, in the Nilgiri and Palni hills on wheat and barley crops, first as well as the second. It has also been observed in Kashmir on self-sown wheat and barley or their tillers during summer. The

writer [Mehta, 1923] stated that the uredospores of this rust suffer most from heat. In the course of these studies also, it was observed that even at Simla this rust did not flourish during summer and was often difficult to find on self-sown plants. Unlike the other two, its uredospores showed poor viability during May-June. Range of monthly average maximum and highest temperatures during summer (April-June) for three years 1935-37 at representative stations in the hills is given in Appendix B. Detailed information regarding collections of viable uredo-material of *P. glumarum* occurring on self-sown wheat, barley or their tillers during summer is given in Tables I-VI and IX. In Tables III-V and VII-IX, only approximate altitudes of places where observations were actually made are given.

TABLE I

Summary of data regarding the occurrence of viable uredospores of wheat rusts at Simla and its neighbourhood on self-sown plants, tillers or stubble throughout the year, based on seven years' intensive study

Altitudes ... ... 6,000-7,000 ft. above sea level

Period of sowing ... ... October-November

Period of harvesting ... ... May-June

Month	Black rust	Brown rust	Yellow rust
	Found during		
June	5 years	2 years	5 years
July	6 ,,	2 ,,	3 ,,
August ...	7 ,,	7 ,,	6 ,,
September ...	7 ,,	7 ,,	7 ,,
October ...	6 ,,	7 ,,	7 ,,
November ...	6 ,,	6 ,,	7 ,,
December ...	6 ,,	6 ,,	7 ,,
January ...	3 ,,	5 ,,	4 ,,
February ...	4 ,,	4 ,,	3 ,,
March	2 ,,	4 ,,	3 ,,
April	None of the years	1 year	1 year
May	2 years	1 ,,	2 years

TABLE II

Summary of data regarding the occurrence of viable uredospores of wheat rusts at higher altitudes in the Simla hills on self-sown plants, tillers or stubble in summer and at the time of new sowing, based on casual observations only

Altitudes ... ... 7,500-9,200 ft. above sea level
Period of harvesting ... ... June-July
Period of new sowing ... ... October

Month	Number of years observations were made	Number of years rust was found		
		Black	Brown	Yellow
June	4	4	1	3
July	1	1	1	1
August	1	1	×	1
September ...	2	2	1	2
October ...	3	2	3	3

× Indicates absence of rust

TABLE III

Summary of data regarding the occurrence of viable uredospores of wheat rusts at lower altitudes of Simla hills on self-sown plants, tillers or stubble, based on casual observations at different times of the year

Altitudes ... ... 3,000-6,000 ft. above sea level
Period of harvesting ... ... April-May
Period of new sowing ... ... October-November

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
June, 1930 ...	Kandaghat ...	4,700	Heavy	×	×
	Kotkhai ...	5,000	Mild	×	×
May, 1931 ...	Kandaghat ...	4,700	Heavy	×	×
	Solan	4,900	Heavy	×	×
July, 1931 ...	Kandaghat ...	4,700	Mild	×	×
October, 1931 ...	Kotkhai ...	5,000	×	×	Heavy
June, 1933 ...	Koti	3,000	Mild	×	×

× Indicates absence of rust

TABLE III—*contd.*

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
December, 1933 ...	Kasauli ...	5,800	Moderate	×	Heavy
February, 1934 ...	Kasauli ...	5,800	×	Moderate	×
April, 1935 ...	Dharampore ...	4,800	Traces	×	×
April, 1936 ...	Kasauli ...	5,800	×	Moderate	×
June, 1936 ...	Dharampore ...	4,500	Moderate	×	×
	Kandaghat ...	4,700	Heavy	×	×
	Solan	4,900	Moderate	×	×
March, 1937 ...	Koti	3,600	×	Traces	Traces
	Kandaghat ...	4,700	×	Traces	Traces
	Dharampore ...	4,800	×	Traces	Traces
	Solan	4,900	×	×	Traces
	Kasauli ...	5,800	×	×	Traces

× Indicates absence of rust

TABLE IV

Summary of data regarding the occurrence of viable uredospores of wheat rusts in the neighbourhood of Murree and Dalhousie (Dhaola Dhar Range) on self-sown plants, tillers or stubble during summer and at the time of new sowing, based on casual observations only

Altitudes ... ... 3,000-10,400 ft. above sea level
Period of harvesting ... ... May-June
Period of new sowing ... ... October-November

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
	Murree Hills				
October, 1931 ...	Murree ...	6,350	Heavy	Heavy	×
August, 1936 ...	Company Bagh ...	4,000	Traces	×	×

× Indicates absence of rust

TABLE IV—*contd.*

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rus
	Murree Hills—contd.				
August, 1936– *contd.*	Jawa	5,500	Mild	×	×
	Bansra Gali ...	6,000	Heavy	Mild	×
	Murree ...	6,300	Traces	×	×
October, 1936 ...	Company Bagh ...	4,000	Mild	×	×
	Dhoknet ...	5,500	Mild	×	×
	Bansra Gali ...	6,000	Heavy	Moderate	×
October, 1937 ...	Murree ...	6,300	Mild	×	×
	Dhaola Dhar range				
July, 1935 ...	Bharwain ...	3,200	Mild	×	×
	Kulu	4,000-5,500	Mild	×	×
	Manali ...	6,200	Mild	×	×
	Pulga	7,500	Mild	×	Mild
September, 1936 ...	Keylong * ...	10,400	...	×	Mild
November, 1936 ...	Dalhousie ...	5,000-7,000	Mild	Moderate	Heavy
	Manali ...	6,000-7,300	Moderate	Mild	Heavy
September, 1937 ...	Dalhousie ...	5,000-7,000	...	Mild	Mild
October, 1937 ...	Kulu	4,500	Traces	Traces	...
	Manali ...	6,500	...	Traces	...

* At this place, wheat is sown in April-May and harvested in September

× Indicates absence of rust

TABLE V

Summary of data regarding the occurrence of viable uredospores of wheat rusts in Kashmir and N.-W. F. Province on self-sown plants, tillers or stubble during June-July and September-October, based on casual observations only, in the years 1936 and 1937 respectively

Altitudes ... ... 4,000-9,200 ft. above sea level
Period of harvesting ... ... May-July
Period of new sowing ... ... October-November

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
June, 1936 ...	Ramsu ...	4,000	Mild	×	Mild
	Batote ...	5,000	Heavy	×	Heavy
	Banihal ...	5,300-6,500	Mild	×	Heavy
July, 1936 ...	Mansehra ...	3,000	Moderate	×	×
	Abbottabad ...	4,000	Mild	×	×
	Uri	4,360	Heavy	Moderate	×
	Baramulla ...	5,500	Heavy	×	×
	Viola	5,500	Moderate	Traces	Mild
September, 1937 ...	Batote ...	5,000	Traces	×	×
	Mortand ...	5,600	Moderate	×	×
	Achhabal ...	5,600	Moderate	×	×
	Banihal ...	6,500-7,000	Mild	Mild	Traces
	Pahalgam ...	7,000	Moderate	×	×
	Gund	7,000	Heavy	Traces	×
	Kangan ...	7,000-7,500	Moderate	×	×
October, 1937 ...	Mansehra ...	3,000	Moderate	×	×
	Abbottabad ...	4,000	Mild	×	×
	Pampur ...	5,250	Traces	×	×
	Baramulla ...	5,500	Traces	×	×
	Kangan ...	6,700	Mild	Traces	×
	Sonemarg ...	9,000	Moderate	×	Traces

× Indicates absence of rust

TABLE VI

Summary of data regarding the occurrence of viable uredospores of wheat rusts in the Kumaon hills on self-sown plants, tillers or stubble during summer and at the time of new sowing, based on three years' study and only casual observations for another two years.

Altitudes	3,200-7,600 ft. above sea level
Perod of harvesting	April-June
Period of sowing	October-November

Month	Number of years observations were made	Number of years rust was found		
		Black	Brown	Yellow
May	3	3	2	2
June	4	4	2	4
July	3	3	1	2
August	1	×	1	1
September	3	2	2	2
October	4	4	4	3
November	3	None	2	2

× Indicates absence of rust

As stated in the text, brown rust was found at 3,500 ft. and above. Yellow rust was met with only near Muktesar (7,600 ft. above sea level).

TABLE VII

Data regarding the occurrence of viable uredospores of black rust of wheat at seven places in Central Nepal on tillers and stubble during May 1934

Altitudes	3,000-5,000* ft. above sea level
Period of harvesting	March-April
Period of new sowing	August-September

Serial No.	Name of place	Altitude (in feet)	Nature of infection
1	Ririkhola ...	3,000	Mild
2	Sutraphat ...	3,000	Moderate
3	Chhapaikhola ...	3,000	Traces
4	Kurumkhola ...	4,000	Moderate
5	Bancharekhola ...	4,000	Traces
6	Wangla ...	4,000	Mild
7	Tansing ...	5,000	Mild

* On account of restricted permission, observations at higher altitudes could not be made

TABLE VIII

Summary of data regarding the occurrence of viable uredospores of wheat rusts in Western Ghats (Mahableshwar, Nasik District and the Dangs), Pottangi (Eastern Ghats, Agency Tract) and Mount Abu on self-sown plants, tillers or stubble during April-June, based on casual observations only

Altitudes ... ... 2,000-4,500 ft. above sea level
Period of harvesting ... ... March-Early in April
Period of new sowing ... ... October-November

Month and year	Name of place	Approximate altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
April, 1936 ...	Tarhabad ...	2,500	Mild	×	×
	Mulher ...	2,000	Mild	×	×
	Babulana ...	3,000	Mild	×	×
	Salher	3,000	Mild	×	×
	Chinchali ...	2,000	Mild	×	×
	Mount Abu ...	4,000	Mild	×	×
April, 1937 ...	Deothan and neighbourhood	2,000	Mild	×	×
	Mangur (near Don) and neighbourhood.	2,500	Mild	×	×
	Kanashi ...	2,500	Mild	×	×
	Abhona ...	2,000	Mild	×	×
	Satpur and Manpur.	2,000	Mild	×	×
May, 1934 ...	Potangi ...	3,000-3,500	Mild	Mild	×
	Mahableshwar ...	4,500	Mild	Heavy	×
May, 1935 ...	Kharad ...	2,400	Heavy	×	×
	Mahableshwar (Old and new) ...	4,500	Mild	×	×
May, 1936 ...	Machutar ...	3,500	Mild	×	×
	Kansusa-Khadda ...	3,500	Mild	×	×
	Panchgani ...	4,000-4,200	Mild	×	×

× Indicates absence of rust

TABLE VIII—*contd.*

Month and year	Name of place	Approximate altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
May, 1936—*contd.*	Gutad	4,300	Mild	×	×
	Mahableshwar ...	4,500	Heavy	Heavy	×
May, 1937 ...	Kansusa-Khadda ...	3,500	Heavy	×	×
	Panchgani ...	4,000	Mild	×	×
	Gutad	4,300	Traces	×	×
	Mahableshwar ...	4,500	Heavy	×	×
June, 1934 ...	Deola	2,000	Mild*	×	×
	Rameshwar ...	3,000	Mild*	×	×
	Mulher ...	2,000	Mild*	×	×
	Chinchali ...	2,000	Mild*	×	×
	Babulana ...	3,000	Mild*	×	×
	Waghamba ...	2,500	Mild*	×	×

× Indicates absence of rust
* On stubble only and showing 1·5% germination

TABLE IX

Summary of data regarding the occurrence of viable uredospores of wheat rusts in the Nilgiri and Palni Hills on self-sown plants, tillers or stubble at different times of the year, based on casual observations only

Altitudes ... ... 5,000-7,500 ft. above sea level
Period of first sowing ... ... April-June
Period of first harvesting ... ... September-October*
Period of second sowing ... ... August-October†
Period of second harvesting ... ... February-March

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
March, 1936 ...	Manjur ...	6,000	×	Traces	×
	Ootacamund ...	6,500	×	Mild	Mild

* The late-sown first crop is harvested during November-December
† The sowings of the second crop are sometimes continued up to November
× Indicates no rust on self-sown plants, tillers, etc.

TABLE IX—*contd.*

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
March, 1936—*contd.*	Kotagiri ...	6,000-6,800	×	Heavy	Mild
	Mynellae ...	6,800	Heavy	Moderate	Mild
	Kadanad ...	6,800	×	Mild	×
	Doddani ...	6,800	×	Heavy	Heavy
	Tuneri ...	7,000	×	Moderate	Traces
	Thalliatimandi ...	7,000	×	×	Heavy
	Anihatti ...	7,200	×	Heavy	Moderate
	Nanjanad ...	7,500	×	×	Heavy
March, 1938 ...	Thoddani ...	6,000-7,200	×	Mild	Mild
April, 1937 ...	Aruvangadu ...	6,200	×	Moderate	×
	Adigarhatti ...	6,600	×	×	Mild
	Ketti	6,700	Moderate	×	×
	Anikorai ...	6,800	×	×	Heavy
	Kadanad ...	6,800	×	Moderate	×
	Nanjanad ...	6,850	×	×	Moderate
	Adashola ...	6,900	Moderate	Moderate	×
May, 1934 ...	Coonoor ...	6,000-6,800	Mild	Mild	×
	Ootacamund ...	7,000	×	×	Mild
May, 1936 ...	Poombarai ..	6,000	Mild	Mild	Mild
June, 1936 ...	Thoddani ...	6,900	Mild	×	×
June, 1937 ...	Poombarai ...	6,200	×	Mild	×
	Lourudhupuram ...	6,500	Mild	×	×
July, 1935 ...	Palur	5,000	×	Mild	×
	Kalavare ...	5,500	×	Mild	×
	Kookal ...	5,500	×	Mild	×
	Poondi ...	6,000	×	Mild	Mild
	Mannavanur ...	6,000	×	Heavy	Mild

× Indicates absence of rust

TABLE X—*contd.*

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
September, 1935 ...	Kotagiri ...	5,600	×	Very mild	×
	Ellenhatti ...	6,500	×	Very mild	×
	Ketti	6,800	Mild	Heavy	Heavy
	Vilpatti ...	6,500	×	Mild	×
September, 1936 ...	Kilkavatti ...	6,800	×	Heavy	Heavy
	Ketti	6,800	×	×	Heavy
	Kadanad ...	6,800	×	×	Heavy
	Anikorai ...	6,800	×	Heavy	Heavy
September, 1937 ...	Poombarai ..	6,200	×	Mild	Heav
	Lourudhupuram ...	6,000-6,700	×	×	Mild
October, 1932 ...	Poombarai ...	6,000	×	×	Mild
	Vilpatti ...	6,500	×	×	Mild
	Kadanad ...	6,800	Mild	×	Mild
	Hoobathalai ...	6,800	Mild	×	Mild
	Ketti	6,800	Mild	Mild	Mild
	Baratty ...	6,800	Traces	Mild	×
	Anikorai ...	6,800	Mild	×	Mild
October, 1935 ...	Ootacamund ...	7,000	Heavy	×	×
	Thalliatimandi ...	7,000	Heavy	×	×
October, 1936 ...	Poombarai ...	6,200	×	×	Moderate
	Kaunje ...	6,500	×	Mild	×
	Kodaikanal ...	6,700	×	×	Mild
	Ketti	6,800	Mild	Heavy	Moderate
October, 1937 ...	Kokalada ...	6,000	Mild	×	×
	Manjur ...	6,000	×	×	Mild
	Adigarhatti ...	6,000-6,300	Mild	×	×

× Indicates absence of rust

TABLE IX—*concld.*

Month and year	Name of place	Altitude (in feet)	Nature of infection		
			Black rust	Brown rust	Yellow rust
October, 1937—*contd.*	Nanjanad ...	6,700	Moderate	×	×
	Kallakorai ...	6,900	Moderate	×	×
December, 1931 ...	Kotagiri ...	6,000	Very mild	×	×
December, 1934 ...	Thoddani ...	6,300	×	Moderate	Mild
	Hoobathalai ...	6,500	×	Mild	×
	Ketti	6,700	×	×	Mild
December, 1937 ...	Thoddani ...	6,300	Moderate	×	×
	Adigarhatti ...	6,400	×	Mild	×
	Kilkavatti ...	6,700	×	Moderate	×
	Appukodu ...	6,800	Mild	×	×
February, 1938 ...	Anikorai ...	6,000-7,000	×	×	Heavy
	Kurthukuzhi ...	6,900	×	Mild	×
	Adashola ...	7,000	×	×	Moderate

× Indicates absence of rust

8. WILD GRASSES AS COLLATERAL HOSTS

During these studies, black rust was observed in the uredostage several times on *Bromus patulus* simultaneously with wheat heavily infected with that rust, during May-June at higher altitudes (nearly 8,000-9,000 ft.) in the Simla hills. On subsequent visits during September-October, the aerial parts of this grass, which is an annual, were found to have completely dried up. Black rust was also found on this grass in Kashmir in July, 1936, mixed with rusted wheat crop at altitudes of 6,000-7,500 ft. In September, 1937, some uredo-pustules, in the midst of teleutosori, were observed on a few plants, mostly dried, along with rusted self-sown wheat at altitudes of nearly 7,500 ft. in Kashmir. Another grass, not flowering at the time of the visit, was also found infected with black rust in the same area.

In Kumaon hills, only once *Avena fatua*, another annual grass, showed mild infection with black rust in a rusted wheat field.

There is no previous record of the occurrence of black rust on either of these grasses in India.

Butler [1918] and Butler and Bisby [1931] recorded the occurrence of uredostage of *P. graminis* on *Brachypodium sylvaticum*, *Festuca gigantea* and *Festuca kashmiriana* in the Himalayas, but the 'Specialized Form', of the rust is not mentioned. During these studies, black rust was twice observed on *Brachypodium sylvaticum* at Simla but not on either of the species of *Festuca*. *Brachypodium sylvaticum* is a perennial grass but it was found infected only during May-June, when it was flowering, near miniature plots of rust cultures in the compound of the laboratory at Simla. By the month of July, the aerial parts had completely dried up on both the occasions and fresh shoots formed in the following years were free from rust. There is no record in literature of the occurrence of *P. graminis tritici* on *Festuca*.

Pure cultures of black rust of *Bromus patulus* and *Brachypodium sylvaticum*, grown on their respective hosts, infected wheat and barley but not oats. In the case of *Avena fatua*, for want of seed, a pure culture could not be grown. The uredo material from this host was directly put on wheat, which got infected. It is clear, therefore, that *Bromus patulus*, *Brachypodium sylvaticum* and possibly *Avena fatua* also, are collateral hosts of *P. graminis tritici*, the black rust of wheat.

No evidence could, however, be obtained to establish the propagation of the rust in question, from one season to another, on any of these grasses during the course of these studies. Nor was any infection observed on them prior to the outbreak of rust on wheat or barley.

Yellow rust was also found once on a species of *Agropyron* only but on inoculation, it failed to infect wheat or barley. Butler [1918] and Butler and Bisby [1931] recorded the occurrence of *P. glumarum* on *Phalaris minor* and *Brachypodium sylvaticum* in the Himalayas but it is not certain if these grasses are collateral hosts of yellow rust of wheat and barley. It is proposed to carry out inoculations to make sure if they are infected by yellow rust of wheat. Search for grasses infected with black or yellow rust is being continued.

9. General discussion

The writer has stated in previous articles, referred to above, that the recurrence of rusts of wheat and barley in the plains of this country is of unusual interest. Unlike most of the wheat-producing countries of the world, *Berberis* and *Thalictrum* are totally absent from 95 per cent of the area under those crops and yet epidemics of black and brown rusts recur every year in the plains. Yellow rust is also common in the plains, excepting those of Peninsular India.

The question that naturally arises is, do these rusts survive in the uredostage in the plains during the interval, which happens to be much longer in this country than elsewhere, between harvesting, i.e. March-April and the new sowing in October-November? With regard to countries with a temperate climate, it has already been stated above that except in the case of black rust, the survival (overwintering) of uredospores takes place over the greater part of the area under cultivation and that black rust in those countries originates every year from

infected barberries. Even in Australia where, like India, it is a question of oversummering, it is clear from what McAlpine [1906] and Waterhouse [1920, 1929] have stated that black and brown rusts are present in the uredostage in wheat-growing areas in a viable condition, all the year round. In that country over-summering might not be possible in every locality on account of hot weather, yet the source of infection for the new crop is there, over the greater part. In India, the situation is different because of the extremely hot and dry summer, which follows the harvest, in the plains as a whole and the absence of self-sown plants and tillers.

The rôle of alternate hosts, *Berberis* and *Thalictrum*, which are found only in the hills in this country has been fully discussed in Section II. The relative importance of uredospores, surviving from year to year on volunteer wheat, barley and their tillers, in the annual recurrence of rusts in the hills as well as plains, is briefly discussed below.

(i) Absence of inoculum in the plains at the time of sowing :—

It is unnecessary to repeat in detail the observations made by Butler and Hayman [1906], Butler [1918] or the writer [Mehta, 1929 ; 1931 ; 1933] regarding the inability of uredospores to survive the heat of summer during which the shade temperature in the Indo-Gangetic plain exceeds 110°F., for weeks at a stretch. Even in Peninsular India, the maximum temperature in shade during summer exceeds 100°F., day after day. The soil all over the plains is exposed to still higher temperatures. Butler [1918] observed that five minutes' exposure to moist heat at 113°F. or a few hours' exposure to the sun, when the shade temperature is 95°F. is enough to kill all the uredospores. The writer [Mehta, 1929] carried out a large number of experiments on the viability of uredospores, after exposure to higher temperatures, and came to the conclusion that none of the three rusts of wheat can survive in the uredostage in the plains of India, as a whole. Range of monthly average, maximum and highest temperatures during summer (April-June) for three years, 1935-37 at representative stations in the plains of India is given in Appendix A. The fact, that at a large number of places in the interior of the country and far from any hills, rusts do not ordinarily break out for 3-4 months from the time of sowing, lends further support to the writer's contention that there is no local source of infection in the plains from the previous crop.

In order to make sure that weather conditions for rust appearance are favourable at the time of sowing all over the plains, wheat seedlings were inoculated with uredo-material of black and brown rusts brought down from the hills on several occasions at Agra, which is one of the warmer places, during October-November and the rusts appeared in 7-8 days. These experiments should leave little doubt about the fact that, but for the local absence of inoculum, these two rusts should appear all over the plains within 4-6 weeks from the time of sowing. In the case of yellow rust, only inoculations made towards the end of November were successful,

(ii) Viability of rusts under natural conditions in the hills :—

During these studies, cultures of all the three rusts of wheat were successfully maintained in greenhouses in the laboratory at Simla. Cultures of some of the physiologic races raised from single spores had completed their 100th generation by the end of July, 1938. It is important to mention that, whereas rust cultures thrive at Simla in the greenhouses all the year round, except those of yellow during May-June, it is not possible to grow rusts of wheat in a greenhouse at Agra and on the plains in general, during summer. Rust cultures can be successfully maintained in the plains only during winter (November-March) and that too with artificial cooling of the greenhouse. In addition to pure cultures of different races of each rust that were grown in greenhouses, all the three rusts of wheat were maintained, for a period of nearly seven years, in the uredostage in miniature plots attached to the laboratory at Simla (nearly 7,000 ft. above sea level). At Almora (nearly 5,500 ft. above sea level), such cultures were also kept growing for a period of nearly three years, during 1930-33. Viability of the uredospores of each rust collected from miniature plots was tested ordinarily once a week up to the year 1933 and later on, after every fortnight, throughout the year. The results of germination tests are given in Tables X-XV.

It may briefly be stated that at Almora, yellow rust could not survive during summer (May-September) whereas the other two were able to oversummer in the uredostage. Cultures of yellow rust could not be saved, even under protection, during either of the two summers at Almora and had to be brought, both the times, during September-October from self-sown wheat at Muktesar, nearly 16 miles away and 2,000 ft. higher than Almora itself. It is interesting to note that during winter (November-March) which is rather mild at that altitude, both black and brown rusts showed fairly good viability, i.e. 35-52 per cent and 41-60 per cent respectively.

At Simla too, yellow rust showed, on the whole, poorest germination during the hottest months of the year (May-June) and in the year 1932, only 2 per cent viability was observed in the first week of June, after which the culture was lost and inoculations had to be made early in September, with fresh material. It is very likely that under protection this rust may survive the summer at Simla, in the uredostage or, at any rate, as mycelium within the host. During May-June every year, pure cultures of yellow rust, maintained in the laboratory at Simla, needed special attention and greater amount of cooling of the greenhouse, where they were kept. In order to avoid the loss of any of them, part of the inoculum of each culture was also kept in the refrigerator in sealed tubes. The other two rusts showed very good germination during summer. During the greater part of winter (November-March), yellow rust showed good viability whereas, in the case of black, there was a considerable drop during December-February, the three coldest months. Brown rust also showed poorest germination during January-February but, on the whole, it stood the cold weather better than black.

It is clear from these observations, that normally all the three rusts of wheat are able to oversummer as well as overwinter at altitudes of nearly 7,000 ft. in this country, although yellow rust during summer and the black in winter may just survive. At altitudes of nearly 5,500 ft. yellow rust is unable to survive during summer but in winter all the three seem to thrive. A fairly high percentage of viability, in the case of black and brown rusts at such altitudes during October-November, strongly suggests the probability of a general infection of the wheat crop during that period, at altitudes still lower, i.e. 4,000-5,000 ft. That explains, why at those altitudes in Central Nepal wheat sown in August-September showed as much as 20-40 per cent crop infection so early in the season, i.e. the first week of December. The case of infection of the second crop in the Nilgiris, situated far in the South (sown in August-October), is very similar.

TABLE X

Range of germination of uredospores of black rust of wheat (P. graminis tritici) *from cultures maintained in miniature plots at Simla during 1931-38. Viability of the material was tested once a week for the first two years and subsequently once a fortnight. The altitude of Simla is nearly 7,000 ft. above sea level*

Month	Percentage germination							
	1931	1932	1933	1934	1935	1936	1937	1938
January	...	28—50	2—10	2—5	0—1	20—25	1—15	2—5
February ...	...	40—63	30—60	0—10	0—2	25—30	10	1—2
March	...	60—80	60—80	10—20	5—40	30—50	30—33	10—40
April	...	90—100	70—90	80	50	60—90	25—33	...
May	...	40—100	65—90	80	60—80	80—100	75—90	...
June	...	40—70	30—80	80	40—50	75—80	75—80	...
July	40—75	30—70	80—90	80	50	90	90	...
August	82—100	30—50	60—80	70—80	50—75	90	90	...
September ...	80—95	30—50	60—80	80	80	80	80—90	...
October	50—100	30—60	80	50—75	50—90	80	50—80	...
November ...	25—50	20—40	70	40—50	50	60—75	30—50	...
December ...	20—33	10—30	10—30	10—40	10—50	15—40	10—30	...

TABLE XI

Range of germination of uredospores of brown rust of wheat (P. triticina) *from cultures maintained in miniature plots at Simla during 1931-38. Viability of the material was tested once a week for the first two years and subsequently once a fortnight. The altitude of Simla is nearly 7,000 ft. above sea level*

Month	Percentage germination							
	1931	1932	1933	1934	1935	1936	1937	1938
January	...	40—68	10—30	10—20	5—10	50	25—33	5—10
February ...	...	50—80	60	5—30	5—20	60	30—40	3—5
March		75—85	50—60	30—40	50—60	50—70	50—60	20- 50
April	...	80—85	60—70	60	60—80	80—90	50—60	...
May	...	40—80	50—80	50—60	50—75	60—100	75—80	...
June	...	50	15—50	50—60	5—10	50	50—60	...
July	40—60	40—50	40—60	60—80	25—30	75	60—80	...
August	75—80	40—50	40	60	30—50	75—80	80	...
September ...	100	50—60	60	50—60	60—75	80	80	...
October	60—100	60—70	70	50—60	75	80	50—75	..
November ...	40—60	70—80	80	60—75	75	80—90	50	...
December ...	30—50	30—80	30—60	25—60	50—75	40—60	30—50	...

TABLE XII

Range of germination of uredospores of yellow rust of wheat (P. glumarum) *from cultures maintained in miniature plots at Simla during 1931-38. Viability of the material was tested once a week for the first two years and subsequently once a fortnight. The altitude of Simla is nearly 7,000 ft. above sea level*

Month	Percentage germination							
	1931	1932	1933	1934	1935	1936	1937	1938
January	...	90—100	15—60	20—40	10—20	75—80	90—100	60
February ...	...	82—90	40—50	10—50	10—30	90	100	50

TABLE XII—*contd.*

Month	Percentage germination							
	1931	1932	1933	1934	1935	1936	1937	1938
March	...	60—77	25—50	50—60	60	90	90	80
April	...	30—40	30—50	30—40	60—75	90	75—90	...
May	...	3—40	10—50	30	10—90	50—90	25—50	...
June	...	0—2	5	10	1	30	1—5	...
July	30—35	10—15	10	20—30	2—5	50	5—30	...
August	33—68	15—25	10	40—50	5—30	50	40	...
September ...	70—95	30—40	10—40	30—60	50—75	60—65	50—60	...
October	50—80	40—70	30	30—50	100	70—75	60	...
November ...	50—90	70	50	50—60	90—100	80	70—80	...
December ...	98—100	40—80	60	40—60	75—100	80—90	80—90	...

The germination recorded against July and August 1932 was obtained from the material on barley, growing near the miniature plots. As stated in the text, culture on wheat was lost in June and re-started early in September that year.

TABLE XIII

Range of germination of uredospores of black rust of wheat (P. graminis tritici) *from cultures maintained in the miniature plots at Almora during 1930-33. Viability of the material was tested once a week. The altitude of Almora is nearly 5,500 ft. above sea level*

Month	Percentage germination			
	1930	1931	1932	1933
January	...	35—45	40—50	80
February	...	30—45	30—40	40
March	...	25—60	50	40—50
April	...	50—60	50—60	...
May	...	40—55	50—60	...
June	...	60—70	40—60	...
July	...	40—80	60	...

TABLE XIII—*contd.*

Month	Percentage germination			
	1930	1931	1932	1933
August	...	60—80	60—70	...
September	...	40—60	60	...
October	35	40—60	50	...
November	30—40	50—60	40—50	...
December	35—40	30—50	30—40	...

TABLE XIV

Range of germination of uredospores of brown rust of wheat (P. triticina) *from cultures maintained in the miniature plots at Almora during 1930-33. Viability of the material was tested once a week. The altitude of Almora is nearly 5,500 ft. above sea level*

Month	Percentage germination			
	1930	1931	1932	1933
January	...	40—60	40—60	30—40
February	...	35—50	40—50	50
March	...	40—60	50—60	50—60
April	...	50—60	50—60	...
May	...	30—40	40—60	...
June	...	50	15—25	...
July	...	50	30—60	...
August	...	40—60	60—70	...
September	...	50—70	60	...
October	50	60	50—60	...
November	30—50	60	50	...
December	50—60	40—50	40—50	...

TABLE XV

Range of germination of uredospores of yellow rust of wheat (P. glumarum) *from cultures maintained in the miniature plots at Almora during 1930-33. Viability of the material was tested once a week. The altitude of Almora is nearly 5,500 ft. above sea level*

Month	Percentage germination			
	1930	1931	1932*	1933
January	...	40—70	50—60	50
February	...	50—65	70	60
March	...	40—65	50—60	60—70
April	...	25—50	15—40	...
May	...	0—5	2—10	...
June	...	×*	0*	...
July	...	×	×	...
August	...	×	×	...
September	...	×	×	...
October	×	50	×	...
November	×	50—60	50—60	...
December	30	50—60	50—60	...

* The culture died and was re-established with material from Muktesar (7,600 ft. above sea level).

× Indicates absence of rust

(iii) Occurrence of uredospores in the hills at the time of sowing :—

Throughout summer, towards the close of the monsoon as well as during autumn (October-November) when the new crop is sown, all the rusts under reference are found in plenty in the hills at altitudes suitable to each, as would be clear from the tables given in connection with the oversummering of rusts. As a matter of fact, these rusts are found in the uredostage for the greater part of the year at altitudes of nearly 6,000-8,000 ft. and, as stated above, the black and brown are also able to oversummer at nearly 4,000-6,000 ft.

(iv) Early outbreaks of rusts in the hills :—

Reference has already been made to the occurrence of abundance of rusts on the first wheat crop in the Nilgiris during August-September, i.e. nearly two

months before sowing in the plains of Peninsular India. It has also been stated that the second wheat crop is sown in the Nilgiris during August-October, which in turn gets infected before sowing in the plains. At altitudes of 4,000-5,000 ft. in Central Nepal also, the outbreak of rusts takes place very much earlier than in other hills because of early sowing which, as stated before, is done in August-September. In fact, both in the Nilgiris and Central Nepal, there is a fairly well-advanced infection on the wheat crop, before the time of sowing in the plains all over the country. In Kumaon and Simla hills as well as near Dalhousie (Dhaola Dhar Range) the new crops of wheat (sown in October) were found infected with yellow rust as early as November. In one case, near Simla, the wheat crop sown early in October showed a fair amount of infection on the 31st of that month. It is important to mention that in all these cases rusted volunteer wheat was found growing within a few feet of the new crops. The earliest outbreak of brown rust on the new crop at Simla was observed on the 15th November, 1938, but up to March 15th following there was only 10 per cent crop infection in the same field, evidently due to a very much longer incubation period during winter at that altitude than in Central Nepal, referred to above.

(v) Late outbreaks of rusts in the hills :—

During these studies, several cases of rust outbreaks in the hills as late as March-May were observed particularly at the higher altitudes, i.e. 7,000 ft. and above. In fact, at those altitudes only yellow rust was noticed in the earlier part of the season, November-December and outbreaks of the other two rusts were always late. As stated before, only once brown rust was noticed at Simla on the new crop in the month of November but its spread was far too slow. Normally, brown and black rusts were not found on the new crop before February and March respectively, in the neighbourhood of Simla. At Muktesar, 7,600 ft. in the Kumaon hills, brown and black rusts were never observed on the new crop before April-May. On the way to Narkunda these two rusts were observed only in traces during May and at Narkunda (9,200 ft. above sea level) during May-June. It is interesting to note that yellow rust was found in abundance at the higher altitudes during April-May, when the other two were either absent or occurred only in traces. At Simla, yellow rust is found almost in epidemic form every year, by the end of March or early in April. It breaks out as early as November-December in the neighbourhood of Simla.

In this connection, it is necessary to point out that the length of the incubation period at Simla during December-February, the three coldest months, was found to range between 10-16, 12-20 and 15-26 days in the case of yellow, brown and black rusts respectively. It is evident that on account of very low temperatures during winter, the mycelium of the parasites concerned grows by fits and starts at the higher altitudes, except in cases of infection that might take place during October-November. The writer [Mehta, 1928] described a similar situation with regard to yellow and brown rusts in the neighbourhood of

Cambridge, where overwintering of black rust is not possible. Range of monthly average maximum and minimum temperatures during November-February at representative stations in the hills of India for three winters (November, 1985-February, 1988) is given in Appendix C.

(vi) Incidence of rusts in the hills in relation to outbreaks in the plains :—

In Section II, the rôle of *Berberis* and *Thalictrum* has been fully discussed and the writer reiterated his previous contention that, as far as the plains are concerned, *Berberis* and *Thalictrum*, the alternate hosts of black and brown rusts respectively, play little part in their yearly origin. It will also be clear from what has been said before in this section that black and brown rusts, in all probability, break out first at comparatively low altitudes, where, on account of milder winter, their uredospores occurring at the time of sowing cause infection on the new crop rather early in the season (November-December). If wheat is sown at such altitudes ' out of season ' (April-June or August-September instead of October-November), these rusts will break out still earlier and, on account of more favourable weather, there would be well-advanced infection by the time the normal crops are sown. The case of yellow rust is different because it cannot oversummer at the lower altitudes and reference has also been made to its early outbreaks (November—December) on the new crop at Simla and places similarly situated.

In the Nilgiris, however, yellow rust breaks out simultaneously with the other two on the first crop (sown in April-June) because that crop is sown only at the higher altitudes (6,000-7,000 ft.) where it can stand the weather. It appears, therefore, that from year to year there is enough inoculum in the shape of uredospores of all the three rusts of wheat on crops in the hills, black and brown at lower and the yellow at higher altitudes, near about the time of sowing in the plains, as far as the northern and central parts of the country are concerned. With regard to the South, on account of a still milder weather in the Nilgiris, for the same altitude, and because of the April-June crop, all the three rusts are found in abundance even before the crop in the plains is sown. The writer [Mehta, 1988] pointed out the existence of foci due to oversummering of rusts in the uredostage in the Siwalik range, Murree hills, Western Ghats, Nilgiris and Palnis. Since then, Nepal and Kashmir, two large hilly areas in the North of India have been added to the list, the former being more serious due to early sowings.

On the strength of observations extending over a period of fifteen years, the writer is able to state that, in general, rusts break out earlier at the foot-hills and plant for plant there is heavier infection at those places than in the neighbouring palnis. Further, that the periods of rust appearance at foot-hills as well as the plains in different parts of the country are not the same.

Considering the length of the Himalayan range, it is clear that any particular station at the foot-hills and those in the neighbouring plains situated along the

course of an early wind laden with inoculum may develop rust, subject to favourable weather, considerably earlier than others.

It is also evident that the dates of rust appearance at any station at foot-hills or the plains may not be the same in any two years and that the dissemination of inoculum from some of the hilly areas may take place much later than from others in accordance with the periods of prevailing winds.

The earliest and usual periods of rust appearance at some of the stations at foot-hills and in the plains based on 15 years' study in the United Provinces and 7-10 years' in other parts of the country are shown in Tables XVI and XVII respectively.

TABLE XVI

Earliest dates and the usual period of rust appearance at representative foot-hill stations

Station	Black rust		Brown rust		Yellow rust	
	Earliest	Usual	Earliest	Usual	Earliest	Usual
Punjab						
Hoshiarpur ...	1st week Feb.	2nd week Feb.	1st week Jan.	1st week Feb.	5th Jan. ...	Jan.-Feb.
Gurdaspur ...	17th Mar. ...	4th week Mar.	4th Dec. ...	2nd week Mar.	27th Dec. ...	2nd week Jan.
Rawalpindi ...	3rd week Mar.	3rd week Apr.	3rd week Mar.	2nd week Apr.	19th Jan. ...	Feb.-Mar.
N.-W. F. Province						
Peshawar ...	27th Feb. ...	1st week Mar.	2nd week Jan.	2nd week Jan.	1st week Feb.	3rd week Feb.
United Provinces						
Gorakhpur ...	30th Dec. ...	2nd week Jan.	16th Dec. ...	4th week Dec.	31st Dec. ...	4th week Jan.
Haldwani ...	4th week Feb.	1st week Mar.	3rd week Jan.	2nd week Feb.	2nd week Jan.	1st week Feb.
Dehra Dun ...	18th Mar. ...	3rd week Mar.	23rd Feb. ...	4th week Mar.	21st Dec. ...	1st week Jan.
Bombay-Deccan						
Niphad	3rd Dec. ...	1st week Jan.	×	×	×	×
Poona	2nd week Nov.	Dec.-Jan. ...	×	×	×	×
Mysore						
Chitaldroog ...	22nd Oct.†	Dec.-Jan. ...	×	×	×	×
Mandya	16th Oct.‡ ...	Dec.-Jan. ...	16th Oct.‡ ...	2nd week Jan.	×	×
Madras						
Coimbatore ...	10th Sept.§	1st-3rd week Feb.	28th Sept.§	2nd week Dec.	×	×

× Indicates absence of the rust concerned
† On early wheat crop, sown in August, 1935
‡ On wheat sown in a miniature plot in August, 1935, at the request of the writer
§ On wheatwn in miniature plots during June-July, 1937, at the request of the writer

Table XVII

Earliest dates and the usual period of rust appearance at representative stations in the plains

Station	Black rust		Brown rust		Yellow rust	
	Earliest	Usual	Earliest	Usual	Earliest	Usual
Punjab						
Karnal	27th Feb. ...	1st-2nd week Mar.	15th Jan. ...	4th week Jan.	7th Jan. ...	2nd-3rd week Jan.
Lyallpur ...	1st week Mar.	3rd week Mar.	3rd week Jan.	3rd-4th week Mar.	20th Dec. ...	Jan.-Feb.
Delhi						
Delhi	22nd Feb. ...	3rd week Mar.	15th Feb. ...	4th week Feb.	2nd Feb. ...	1st week Feb.
Sind						
Sakrand	28th Feb. ...	2nd-3rd week Mar.	4th Mar. ...	2nd week Mar.	26th Feb. ...	End of Feb.-Mar.
United Provinces						
Agra	6th Feb. ...	3rd week Feb.	18th Jan. ...	1st week Feb.	3rd Jan. ...	2nd-3rd week Feb.
Cawnpore ...	4th week Dec.	1st-2nd week Feb.	1st week Feb.	Feb.-Mar. ...	1st week Feb.	Feb.-Mar.
Benares	27th Jan. ...	End of Jan.-Feb.	19th Jan. ...	3rd-4th week Jan.	19th Jan. ...	End of Jan.-Feb.
Bihar						
Pusa	31st Jan. ...	2nd week Feb.	9th Dec. ...	4th week Dec.	7th Jan. ...	Jan.-Feb.
Sabour	2nd week Feb.	1st week Mar.	1st Jan. ...	2nd-3rd week Jan.	23rd Jan. ...	4th week Jan.-Feb.
Central Provinces						
Jubbulpore ...	28th Jan. ...	3rd week Feb.	19th Jan. ...	1st week Feb.	17th Feb. ..	4th week Feb
Hyderabad-Deccan						
Parbhani	15th Dec. ...	2nd-3rd week Jan.	×	×	×	×
Hyderabad ...	9th Dec. ...	Jan.-Feb. ...	1st week Jan.	Jan. ...	×	×
Bombay-Deccan						
Dharwar	21st Nov. ...	Dec.-Jan. ...	15th Jan.† ...	×	×	×
Madras						
Bellary	14th Nov.‡ ...	1st week Jan.	×	×	×	×

× Indicates absence of the rust concerned
† This rust was observed only once at Dharwar
‡ On early crop sown in August-September

It is necessary to mention that in the case of some of the stations, the dates quoted in Tables XVI and XVII are those on which the rust in question was actually observed and may not necessarily be the date of first appearance. Information obtained from such stations stated that the rust concerned was observed in traces or 10 per cent crop infection was found on a particular date or during the week.

There is nothing to suggest that any station in the plains shown in Table XVII got its rust from a particular place at foot-hills or along any special direction from the hills.

(vii) Rust outbreaks in the plains due to wind-blown uredospores :—

In view of the absence of a local source of infection in the plains, where, as stated before, rusts do not normally appear for 3-4 months from the time of sowing, it is clear that rusts are re-introduced every year from some source. It has also been stated above that plenty of rust inoculum is present in the hills at the time of wheat and barley sowings in the plains. The most obvious source of infection, therefore, seems to lie in the hills and it is right to conclude that rust outbreaks are caused in the plains by uredospores blown down by wind from such foci. Dissemination of rusts from foci, referred to in this section, does not call for any explanation, because the actual distance to the foot-hills could be easily covered by winds of average velocity in 2-3 hours, although by the circuitous hill-paths it appears to be considerably longer. The writer [Mehta, 1929] made detailed reference to the observations of Newton [1922] and Gussow [1926] regarding the dissemination of black stem-rust by wind from U. S. A. to Canada. As stated therein, Shitikova-Roussakova [1927] gave a similar explanation of the spread of brown and black rusts to the Amur region in U. S. S. R. from North Manchuria, where they are able to overwinter in the uredostage. Reference was also made to the observations of Stakman [1927], relating to the possibility of infection of cereals by uredospores of black stem-rust, blown by southern winds to the North in U. S. A., where that rust is unable to overwinter. Stakman [1934] also referred to Mexico and Texas as the source of inoculum in the form of uredospores for the northern states of U. S. A. In his Summary Report of Rust Epidemiology for the year 1937-38, this author made similar observations regarding the spread of black stem-rust from Southern Mexico.

The writer [Mehta, 1933] gave an account of the study of rust dissemination with the help of aeroscope slides, and those sent up on kites and balloons, along with tables supplying dates of rust appearance at various stations. During the last five years, slides were exposed at as many as 54 representative stations and spores of each rust were caught from the air, well before its appearance on the local crop, at most of them.

The similarity between the physiologic-race flora of hills and the plains is another proof, and a strong one too, of the fact that the source of all the three rusts under reference lies in the hills. With the exception of race 21 of black

rust and 108 of brown, which were found in one and two collections respectively from the plains only, all the physiologic races occurring in plains were also met with in collections from hills and hilly tracts as shown in relevant tables of Section One.

Information regarding wind-trajectories of representative stations in the country as well as data obtained from the study of aeroscope slides will be supplied in due course in an article dealing with Rust Dissemination.

(viii) Conclusion :—

The observations recorded above indicate clearly that, in the plains of India, rust inoculum is killed by the heat of summer, from year to year, soon after the harvest and that at the time of sowing, there is no local source of infection. Further, that in the hills, due to cooler weather, the rusts under reference are able to survive during summer in the uredostage on volunteer wheat and barley as well as their tillers. These uredospores seem to be the most obvious source of infection for new crops in the hills. It is such outbreaks in the hills that supply inoculum for crops in the plains, after dissemination by wind, as early as December-January. In short, rusts are largely propagated by uredospores from season to season in this country. The rôle of uredospores in the annual recurrence of rusts in India, as a whole, is, therefore, of outstanding importance and far more potent than that of alternate hosts, i.e. *Berberis* and *Thalictrum*, in the case of black and brown rusts, respectively.

(ix) Means of combating rusts :—

In view of the fact that the source of all the rusts under reference lies in the hills, it is clear that they should be effectively controlled by the cultivation of resistant varieties in the hills only, i.e. over less than 5 per cent area.

At the same time, one has to reckon with the difficulty of breeding a wheat that would be resistant to all the three rusts because, from the point of view of damage, they are equally important in the country, as a whole. Anyhow, this project will take a long time.

It is necessary, therefore, that in the meanwhile wheat and barley crops should be saved from devastating epidemics, year after year, caused by all the three rusts taken together, by controlling the inoculum at the source, i.e. in the hills. Considering the huge loss of Rs. 60 millions or so per year to these crops caused by rusts, the writer is strongly of the opinion that a good deal of damage could be mitigated by rigorous destruction of self-sown plants and tillers, which 'carry over' the rusts, 1-2 months before sowings in the hills. This method is thoroughly practicable because of very small individual holdings in the hills, where the crops in question are grown on small and narrow terraces.

Destruction of self-sown plants and tillers should also reduce considerably the possibility of the formation of viable teleutospores early in winter and of the infection of alternate hosts therefrom.

As far as Peninsular India is concerned, the foci for which are circumscribed, a huge sum of money could easily be saved by suspending only the cultivation of the first crop of wheat and barley (sown in April-June) in the Nilgiri and Palni hills. There is little doubt about the fact that rust outbreaks in the Hyderabad State as well as over a considerable part of Bombay-Deccan are caused by the inoculum present in abundance in those hills at the time of sowing in the plains. Hyderabad and Bombay-Deccan cover an acreage of over 2 millions under wheat alone, whereas there are hardly 3,400 acres in the Nilgiri and Palni hills, taken together, under wheat and barley. It is necessary that sowings of wheat done in the districts of Chitaldroog and Bellary during July-August should be delayed, because crops sown so early act as secondary foci to the neighbouring areas.

It should also be possible to check effectively rust outbreaks in the Indo-Gangetic plain, which covers the largest tract under wheat cultivation, by prohibiting August-September sowings of wheat and barley in Nepal. These crops should be sown at the usual time, i.e. October-November. The Nepal range is undoubtedly the most dangerous focus for crops in the Indo-Gangetic plain.

By far the most effective method of control would be the suspension of wheat and barley cultivation for 2-3 years in the hills, at altitudes of 3,000 ft. and above, where rusts are able to oversummer. This method was suggested by the writer [Mehta, 1929] but the hilly areas are under the control of different governments, without whose co-operation it would be difficult to carry it out. There is no reason, however, why in the meanwhile the other measures outlined above should not be brought into force and the writer feels convinced that, although rusts may still appear here and there after their adoption, they should not break out early enough to cause epidemics over large tracts in the plains, as happens at present.

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11. Summary

A summarized account of oversummering of rusts in the hills of India, in relation to their annual recurrence, was published by the writer in two previous articles. Since the year 1930, the scope of the study has been extended, from time to time, to include new areas and this section supplies data obtained from different parts of the country, up to the end of March, 1938. In addition to observations on the incidence of rusts, influence of weather conditions on the viability of uredospores in the hills, throughout the year, was studied from rust cultures grown in miniature plots.

Further evidence of oversummering of all the three rusts of wheat as well as of black and yellow rusts of barley has been obtained from several places in the hills. With regard to their annual recurrence in plains as well as the hills, it may briefly be stated that :—

(i) There is no local source of infection, from the previous crop, in the plains of India, at the time of sowing. All uredospores are killed, year after year, after the harvest because of high temperatures during summer.

(ii) On account of milder weather, uredospores of all the rusts, under reference, are able to survive the summer on self-sown plants and tillers, at various altitudes in the hills.

Black rust of wheat was also found on four wild grasses but no evidence could be obtained of its propagation in the uredostage, from one season to another, on any of them.

(iii) Study of the viability of uredospores from rust cultures, grown in miniature plots, has conclusively proved that all the three rusts of wheat are able to oversummer as well as overwinter, at altitudes of nearly 7,000 ft.

(iv) On several occasions, rust outbreaks have been observed after 4-6 weeks of sowing of the new crop in the hills, due to the presence of a large number of rusted volunteers within a few yards of the fields.

There is plenty of uredo-material at suitable altitudes in the hills at the time of new sowings.

Well-advanced infection with rusts on early crops in the hills has also been observed long before their outbreaks in the plains.

(*v*) Recent studies have further strengthened the writer's contention that black and brown rusts of wheat are, in all probability, disseminated from comparatively low altitudes where, on account of milder winter, their uredospores occurring at the time of sowing, cause infection on the new crop rather early in the season. Two important foci, where, due to earlier crops, there is plenty of

inoculum, year after year, at the time of sowings in the plains, have been located. For several years, these two rusts have been found to break out in the plains as early as December-January, i.e. 3-4 months prior to the period of the earliest possible infection of their alternate hosts, which are found only in the hills.

In the case of yellow rust, the inoculum must be blown down originally from higher altitudes, because normally, it is unable to survive the summer below 6,000-7,000 ft.

(vi) In general, rusts have been observed to appear much earlier and plant for plant there is heavier infection at foot-hills than at places further off.

(vii) Rusts are largely propagated by uredospores from season to season in the hills. The rôle of uredospores in their annual recurrence, therefore, is a factor of outstanding importance and far more potent than that of alternate hosts, i.e. *Berberis* and *Thalictrum*, in the case of black and brown rusts, respectively.

(viii) In so far as the source of all the rusts under reference lies in the hills, cultivation of resistant varieties in those areas only should be an effective control. Till a variety or varieties that can resist all the three rusts of wheat are produced it seems necessary that a considerable part of the huge loss due to rusts, year after year, be saved by the adoption of other methods, suggested by the writer.

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APPENDIX A

Range of monthly Average maximum and Highest temperatures, in degrees Fahrenheit, in shade during summer (April-June) for three years 1935-37 at representative stations in the plains of India

Station	April		May		June	
	Average max.	Highest	Average max.	Highest	Average max.	Highest
Punjab						
Labore	85—98	99—1050	103—109	113—116	101—109	114—117
Delhi						
Delhi	90—97	104—19	103—107	111—113	96—107	109—113
United Provinces						
Agra	94—100	106—110	107—110	113—117	100—109	112—115
Allahabad	98—102	109—111	106—111	114—116	99—108	109—114
Bihar						
Patna	97—101	107	99—106	109—111	92—100	98—113
Central Provinces						
Nagpur	94—104	108—111	107—111	113—115	93—102	106—113
Hyderabad-Deccan						
Hyderabad (1,709 ft. above sea level)	93—102	102—108	104—107	109—112	91—97	101—110
Bombay-Deccan						
Poona (1,834 ft. above sea level) ...	98—100	104—106	99—100	106—108	86—90	92—101
Mysore State						
Mysore (2,518 ft. above sea level) ...	91—95	96—100	91—94	97—100	84—88	89—96

APPENDIX B

Range of monthly Average maximum and Highest temperatures, in degrees Fahrenheit, in shade during summer (April-June) for three years 1935-37 at representative stations in the hills of India

Station	April		May		June	
	Average max.	Highest	Average max.	Highest	Average max.	Highest
Punjab						
Simla (7,224 ft. above sea level) ...	59—66	74—77	73—76	81—83	71—79	77—84
Kashmir						
Srinagar (5,204 ft. above sea level) ...	61—66	75—77	78—84	87—96	81—89	92—97
Benga						
Darjeeling (7,434 ft. above sea level)	61—62	68—70	63—64	68—69	64—66	68—70
Central Provinces						
Pachmarhi (3,528 ft. above sea level)	87—90	94—97	96—98	100—103	85—89	97—10(
Bombay-Deccan						
Mahableshwar (4,500 ft. above sea level)	84—86	90—93	84—86	90—94	67—73	75—85
Madras						
Ootacamund* (7,364 ft. above sea level)	69—70	74—75	70—71	74—76	63—65	70—73

* Range based only on two years' data, information for 1935 was not available.

APPENDIX C

Range of monthly Average maximum and minimum temperatures, in degrees Fahrenheit, in shade during winter (November-February) for the years 1935-38 at representative stations in the hills of India

Station	November		December		January		February	
	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.
Punjab								
Simla (7,224 ft. above sea level)	56—59	43—46	48—50	36—38	46—48	34—36	46—48	35—37
Kashmir								
Srinagar (5,204 ft. above sea level)	56—58	31—35	42—49	28—33	35—43	23—30	36—52	25—32

APPENDIX C—*contd.*

Station	November		December		January		February	
	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.
Bengal								
Darjeeling (7,434 ft. above sea level)	54—55	44—45	49—52	37—39	43—48	33—38	46—48	36—37
Central Provinces								
Pachmarhi (3,528 ft. above sea level)	74—77	49—54	71—73	45—48	72—75	43—51	73—75	47—53
Bombay-Deccan								
Mahableshwar (4,500 ft. above sea level)	74—75	59—60	73—74	56—58	74—77	57—59	74—78	55—58
Madras								
Ootacamund (7,364 ft. above sea level)	64—65	49—	65—66	41—46	66—69	41—44	66—70	45—47

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